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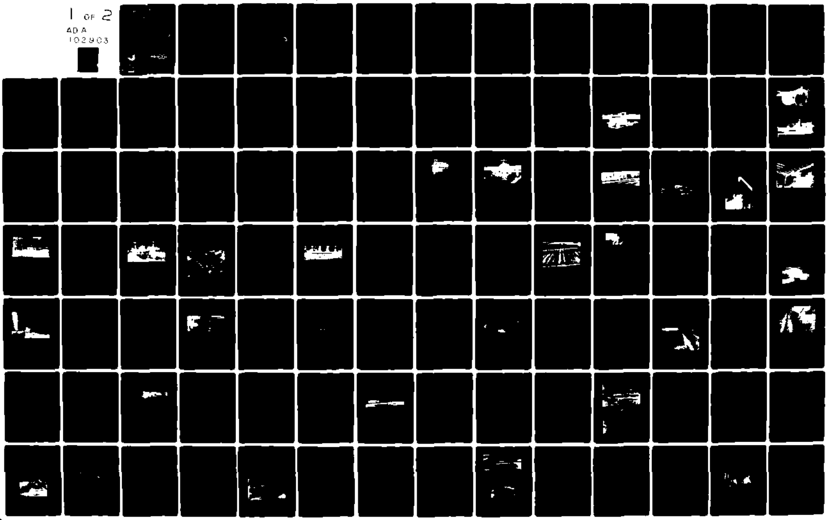

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12

FIELD TEST OF EXPEDIENT PAVEMENT REPAIRS (TEST ITEMS 16-35)

AD A102903

MICHAEL T. McNERNEY
ENGINEERING RESEARCH DIVISION

NOVEMBER 1980

FINAL REPORT
JULY 1978 — SEPTEMBER 1979

AFESC

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1. REPORT NUMBER: ESL-TR-80-51	2. GOVT ACCESSION NO.: AD-A102 903
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): FIELD TEST OF EXPEDIENT PAVEMENT REPAIRS (TEST ITEMS 16-35)	5. TYPE OF REPORT & PERIOD COVERED: Final Report, July 1978-September 1979
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Michael T. McNerney	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Engineering and Services Center, Tyndall Air Force Base, Florida 32403	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: PE-63723F, JON 21042B22
11. CONTROLLING OFFICE NAME AND ADDRESS: HQ AFESC/RDCR, Tyndall Air Force Base, Florida 32403	12. REPORT DATE: November 1980
	13. NUMBER OF PAGES: 108
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office): 12 112	15. SECURITY CLASS. (of this report)
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Availability of this report is specified on verso of front cover.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Temporary, Expedient Airfield Pavement Repair
Bomb Damage Repair
Runway Repair Materials
Unsurfaced Repairs
Polymer-concrete Membranes
Airfield Damage Repair
Soil Compaction
Landing Mat
Polymers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes field tests of 19 repairs that showed potential for use in temporary, expedient repair of bomb craters in runways. The test facility consisted of a concrete surface placed over a crushed limestone base which in turn lay over a weak clay subgrade. Three 20-foot by 20-foot square sections were left open in the concrete to serve as test pits. The test facility was so constructed to allow for simulation of small bomb craters in a typical North Atlantic Treaty Organization runway. The test materials were used to repair the "craters" in the pavement. Upon completion of each repair, the

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20. ABSTRACT (CONCLUDED)

resulting surface was tested with load carts constructed to give the same load that would be experienced from taxiing of a modern fighter aircraft or cargo aircraft. This report describes the result of each of the tests and identifies areas requiring further research.

PREFACE

This report was prepared by the Air Force Engineering and Services Center, Engineering and Services Laboratory at Tyndall Air Force Base, Florida 32403, under Job Order Number 21042B22, Bomb Damage Repair Materials Field Test. The results of this study were used to assist in writing technical guidance to the field users in an earlier technical report (ESL-TR-79-08). Data from these tests combined with data from subsequent tests will be used to write a comprehensive Small Crater Manual.

This report discusses field tests of previously identified small crater repair materials. Limestone and polymer concrete materials were used for repairs of small craters constructed to simulate bomb craters in a typical NATO runway.

This report has been reviewed by the Public Affairs officer (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public including foreign nationals.

This technical report has been reviewed and is approved for publication.

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ABBREVIATIONS AND NOMENCLATURE

Abbreviations

AFESC	Air Force Engineering and Services Center
BA	Butyl Acrylate
BC	Base Course
BP	Benzoyl Peroxide
BS	Beach Sand
CBR	California Bearing Ratio
CH	Heavy Clay as defined in Uniform Soil Classification System
DMPT	N, N-dimethyl-p-toluidine
FOD	Foreign Object Damage
FRP	Fiberglass-reinforced polyester resin
MMA	Methyl Methacrylate
PCC	Portland cement concrete
RRR	Rapid Runway Repair
TMPTMA	Trimethylolpropane Trimethylacrylate

Nomenclature

f_r	Flexural strength
k	Modulus of subgrade reaction
MC	Moisture content
pcf	Pounds per cubic foot
pci	Pounds per cubic inch
psi	Pounds per square inch
rpm	Revolutions per minute
vpm	Vibrations per minute

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SECTION I

INTRODUCTION

1. BACKGROUND

Recent improvements in weapon technology and increased use of hardened aircraft shelters have made attacks against runway pavements an effective method of reducing the effectiveness of an enemy's air power. The U.S. Air Force base civil engineering squadron, supplemented with any available RED HORSE or PRIME BEEF resources, has primary responsibility for temporary, expedient airfield repairs to maintain combat operations. The Air Force has developed and tested a technique of rapid bomb damage repair for runways which uses debris for the crater backfill, a limited thickness of select fill as a base course, and an AM-2 landing mat patch for the repair surface (Reference 1). This technique is oriented primarily toward the simultaneous repair of relatively large bomb craters typically created by conventional, non-nuclear ordnance.

The existing landing mat repair technique may not be adequate for repair of relatively small craters due to the potential roughness problem associated with multiple short mats (References 2 and 3). Also, as the size of the repair area becomes smaller, the use of mats becomes less efficient. Increasing numbers of ramps and anchors are required, and the ratio of mat area to damage area increases rapidly if an entire 50-foot width of a repair strip must be covered by mats. The use of landing mat material for repair of numerous small craters will result in lengthy assembly and anchoring times, will require large volumes of mat, and will pose a potentially severe roughness problem.

2. PHASED APPROACH

In 1976, Detachment 1 (Civil and Environmental Engineering Development Office), Armament Development and Test Center (now redesignated Armament Division), began a three-phase program to develop new techniques for expedient airfield pavement repair for small craters and scabs.

a. Phase 1 Laboratory Experimentation

During Phase 1, laboratory tests and accelerated F-4 load cart trafficking of spalls up to 5 feet in diameter provided preliminary information on candidate repair materials (References 4 and 5).

b. Phase 2 - Field Test of Expedient Pavement Repairs

The initial objective of the second phase was to evaluate the performance of candidate repair materials identified in previous studies. These materials were to be installed using currently available, standard Air Force equipment. Soft clay subgrade, representative of weak crater backfill materials, was used in field testing candidate materials; trafficking of these designs was accomplished with an F-4 load cart to simulate aircraft loading.

After one year of field testing in Phase 2, using standard inventory Air Force equipment and off-the-shelf, commercially available repair materials, none of the designs tested met Air Force requirements. At the conclusion of this testing, a technical report (Reference 6) was produced which documents test items 1 through 15. In essence, the field test of items 1 through 15 constituted the first of two subphases in Phase 2. Phase 2 was then continued with expanded test parameters:

(1) Other than standard inventory Air Force equipment could be used during field trials; and

(2) Polymer concrete, identified by a separate study (Reference 7) as a potential expedient repair material, was to be included in this evolutionary phase of field testing.

This report covers the second half of Phase 2, documenting the results of field testing items 16 through 35. During the course of this subphase, a report was issued to provide field users with an interim procedure for using crushed limestone for crater repairs and Silikal, a polymer concrete, for scab (spall) repairs (Reference 8).

c. Phase 3 - Explosive Crater Field Tests

In August 1979, the most promising repair designs identified in the second half of Phase 2 (i.e., test items covered by this report), were field tested using six exploded craters. These latter tests constitute Phase 3 of the research and development effort which began in 1976. Phase 3, documented by a separate report (Reference 9), was aimed at the attainment of the following objectives:

(1) Evaluation of the performance of selected repair materials by field testing, using load carts to simulate F-4 and C-141 aircraft traffic;

(2) Identification of construction and design problems associated with the use of these materials; and

(3) Identification of the two procedures most suitable for rapid, flush repair of small craters using augmented Air Force equipment.

These two small crater repair methods were then field tested at the Tyndall Air Force Base Explosive Crater Test Facility.

SECTION II

TEST DESCRIPTION

1. TEST FACILITY

A permanent facility was constructed at Tyndall Air Force Base, Florida, by the Air Force Civil Engineering Center, Directorate of Field Technology, to allow accelerated traffic test of various pavement repair materials and designs. A clay core 60 feet wide, 220 feet long, and 6 feet deep was placed and compacted at a high water content to provide a weak test subgrade. Twelve inches of crushed limestone was placed as a base course, followed by a 12-inch-thick Portland cement concrete pavement. Three 20-foot by 20-foot-square sections were left open in the concrete to serve as test pits. The local dune sand was stabilized with oyster shells to construct a sand fill around the test site, and a 10-foot-wide asphalt berm was placed on top of this fill, surrounding the test site. The local water table fluctuates; during wet seasons its level approaches the surface of the natural sand subgrade. Figures 1 and 2 provide plan and cross section views and give the dimensions of the test site.

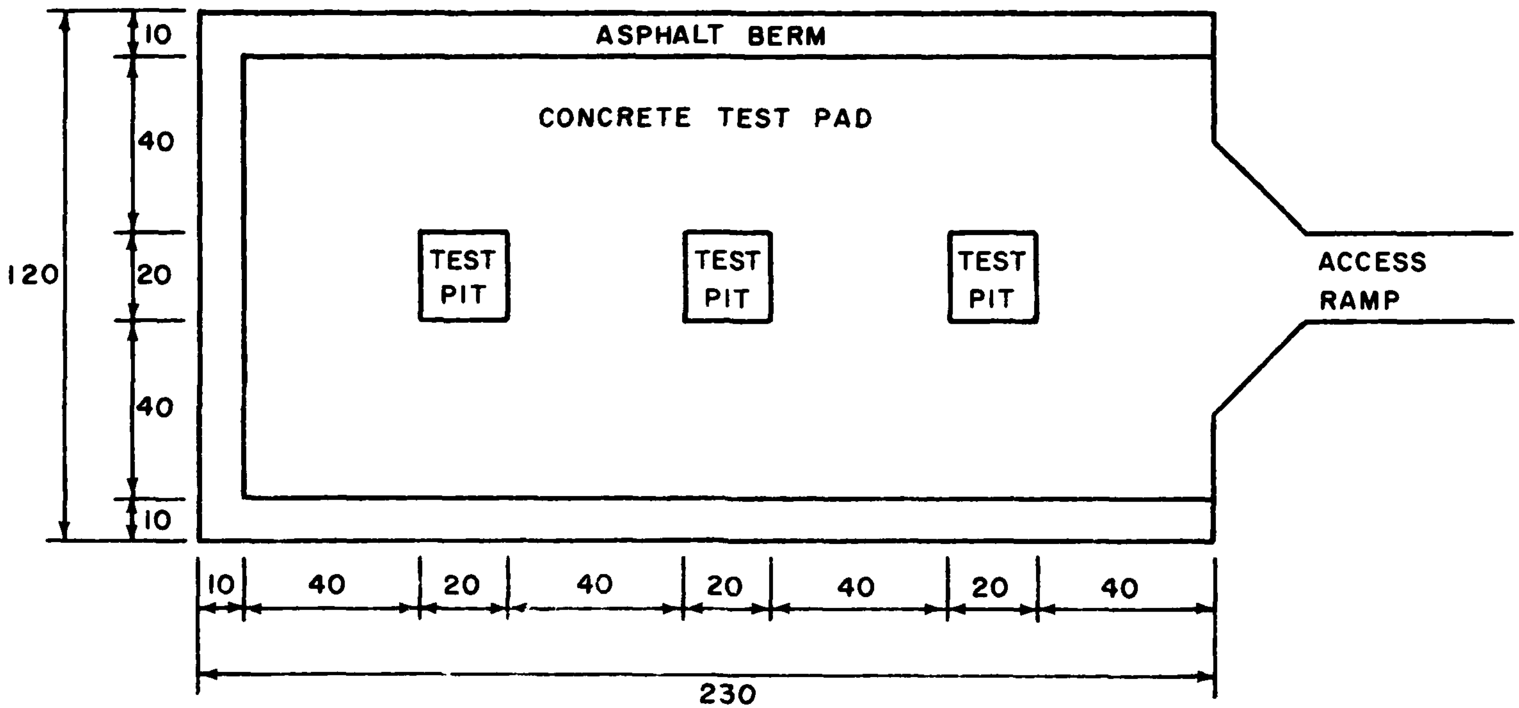
2. RATIONALE FOR DESIGN OF TEST PIT

The 20-foot-square test pits provide a location to construct representative pavement repairs. The depth to the clay subgrade can be varied by adding or removing clay as necessary. Following traffic on any test repair, the repair materials can be removed and a different repair constructed in the same pit.

The test pits were not designed to duplicate the actual crater repair problem. The many possible variations in crater types and sizes and their very erratic geometry (Reference 10) ruled out any attempt to construct models representing craters during the early stages of field experimentation. Instead, the dimensions of the test pits were selected to provide a controlled test of the juncture between the pavement and the repair and to test the repair performance over a soft subgrade with a minimum effect from edge conditions. The test sections are merely a large scale extension of the laboratory permitting direct comparison of results of one test to another. The soft clay subgrade with a California Bearing Ratio (CBR) of 4-7 was kept intentionally weak to represent a worst-case situation, one that might be expected in an actual crater, but the actual density will not likely represent a debris backfill crater. Such an approach requires that promising materials and designs identified under simulated (i.e., test pit) conditions undergo actual (explosion-formed) crater tests to obtain *posteriori* performance data.

3. SUBGRADE MATERIAL

The clay used for the test subgrade was a local clay, classified as CH by the Unified Soil Classification System (Reference 11), obtained from the vicinity of Wewahitchka, Florida. Table 1 shows physical properties and Table 2 lists the mineralogical composition of the clay. Figure 3 is a representative gradation of the material; Figure 4 shows a plot of the material



Dimensions in Feet

Figure 1. Plan View of Test Site

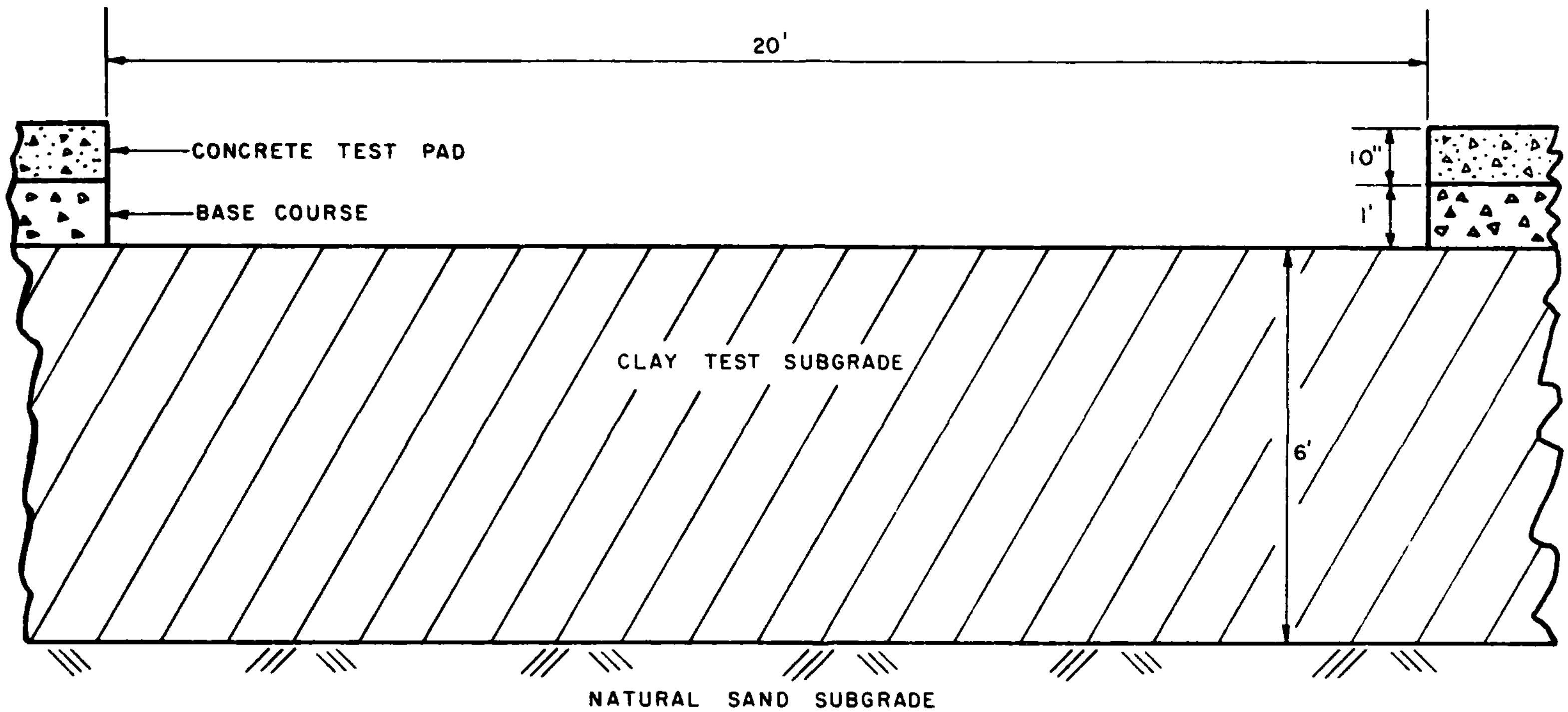


Figure 2. Test Pad Cross Section

TABLE 1. PHYSICAL PROPERTIES OF WEWAHITCHKA CLAY

Property	Range	Average
Liquid Limit	57 - 79 percent	65 percent
Plastic Limit	21 - 30 percent	25 percent
Plasticity Index	30 - 52 percent	41 percent
Specific Gravity	2.58 - 2.67	2.61
CE-55 Optimum Dry Density	110 - 115 pcf[1]	113 pcf
Optimum Moisture	13 - 15 percent	14.5 percent
CE-26 Optimum Dry Density	105 - 109 pcf	107 pcf
Optimum Moisture	13 - 16.5 percent	14.5 percent
CE-12 Optimum Dry Density	98 - 102.5 pcf	99.0 pcf
Optimum Moisture	11.5 - 18 percent	15.0 percent

[1]Pounds per cubic foot.

TABLE 2. MINERALOGICAL COMPOSITION OF WEWAHITCHKA CLAY

Mineral Constituents	Relative Sample Content[1]
Clay	
Kaolinite	Intermediate
Smectite	Common
Clay-mica	Common
Non-Clays	
Quartz	Intermediate
Feldspars	Rare

[1]Based on the following:

Abundant	> 50 percent
Intermediate	25 - 50 percent
Common	10 - 25 percent
Minor	5 - 10 percent
Rare	< 5 percent

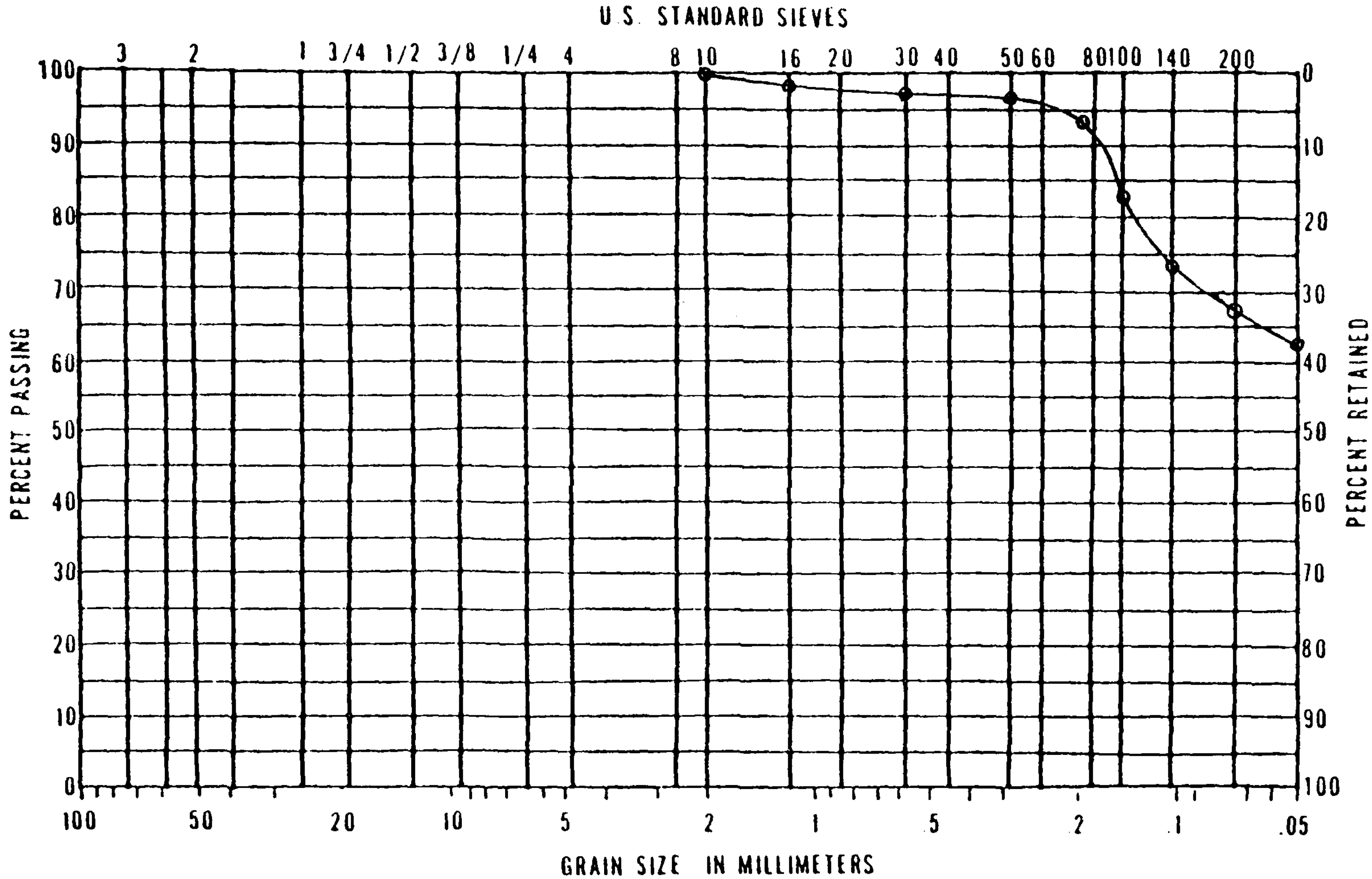


Figure 3. Gradation of Wewahitchka Clay

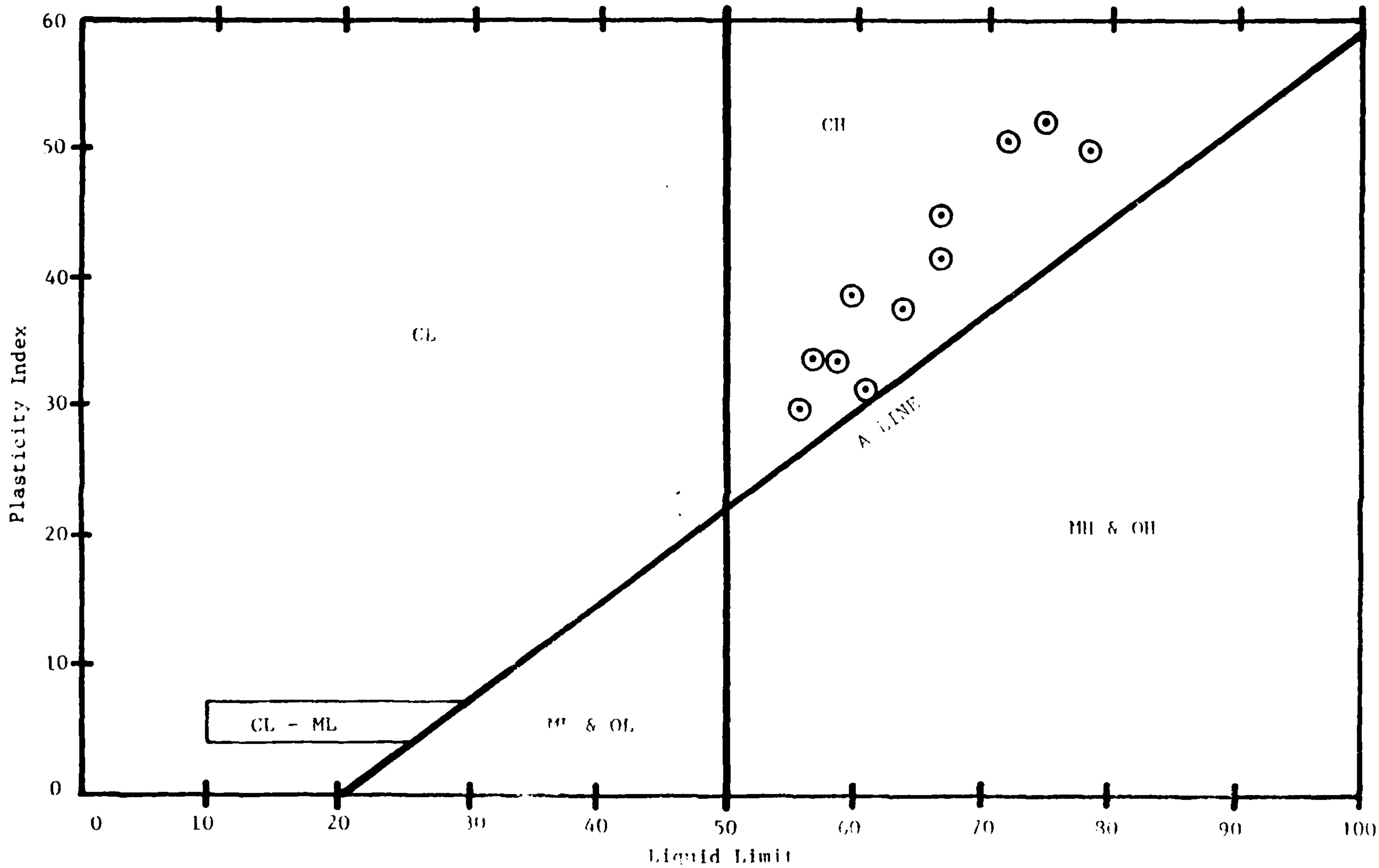


Figure 4. Plot of Wewahitchka Clay on Plasticity Chart

on a plasticity chart. The clay was placed at an average moisture content of 27 percent and a California Bearing Ratio (CBR) of 4. Empirical data derived from eight prior crater repair field tests served as the basis for selecting the aforementioned strength for the test subgrade (Reference 5).

4. TEST SITE SHELTER

From March to May 1979, testing was temporarily halted during construction of a prefabricated building over the site to permit construction and testing of candidate repair materials and designs regardless of the weather.

5. LOAD CARTS USED TO SIMULATE F-4 AND C-141 AIRCRAFT TRAFFIC

a. F-4 Load Cart Traffic

Most of the repairs were subjected to simulated F-4 traffic. The load cart, shown in Figure 5, applies a 27,000-pound main gear load at 265 pounds per square inch (psi) tire pressure.

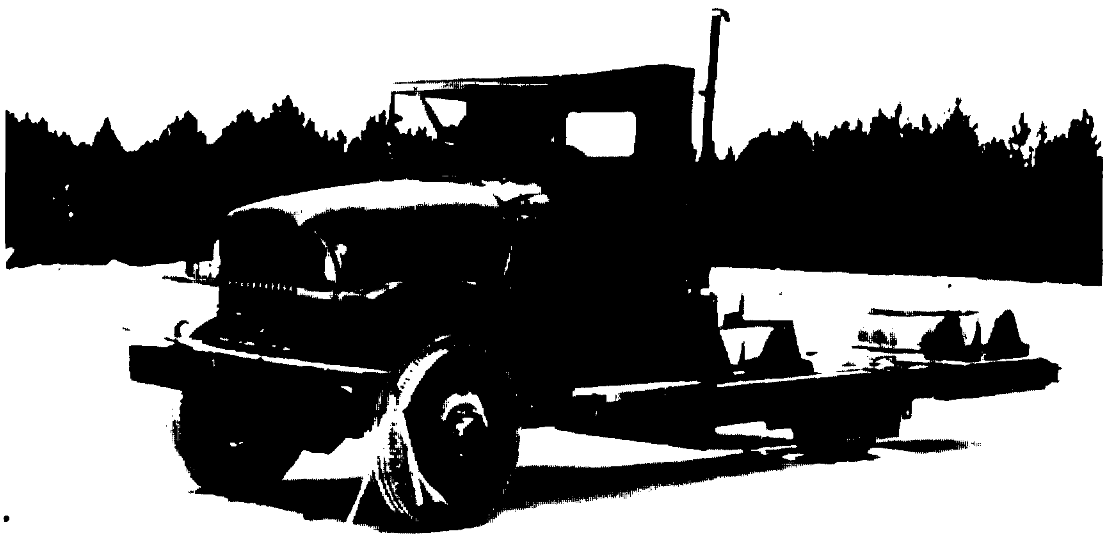


Figure 5. F-4 Load Cart

Traffic was applied in an approximately normal distribution over a 10-foot-wide traffic lane (Figure 6) to give adequate traffic line size and correlate with load cart tests at Waterways Experiment Station (Reference 4).

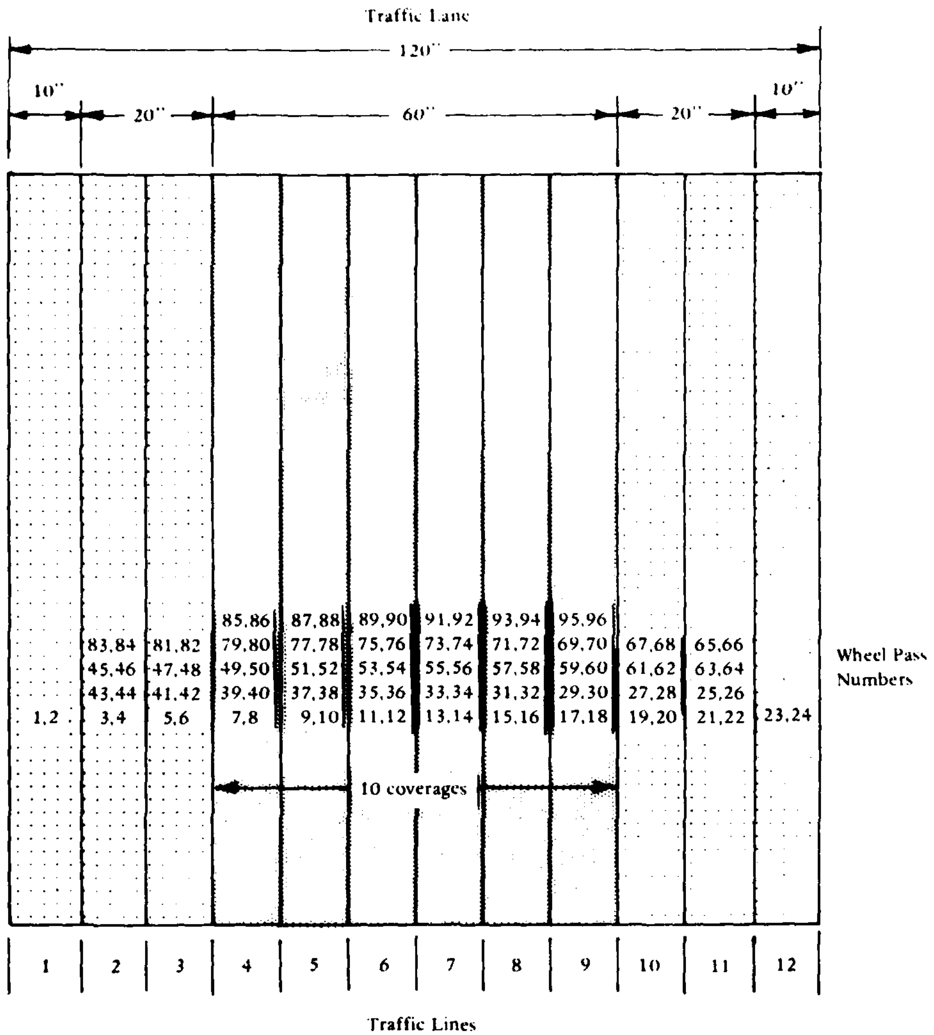


Figure 6. Traffic Distribution Pattern for the F-4 Load Cart

The load cart was driven forward, then backed up in the same wheel path. On the average, a total of 96 passes of the load cart were placed on each test item to obtain ten coverages of the traffic in the six center lanes, with eight coverages in the four adjacent lanes, and two coverages in the two outside lanes. Such a distribution is considered representative of actual aircraft traffic distribution and precludes a sharp discontinuity between trafficked and untrafficked areas (Reference 12). However, the width of actual aircraft traffic distribution depends on whether there are channelized traffic or non-channelized traffic areas. The wider the traffic distribution, the more passes of the aircraft are required to achieve the same number of coverages. The reported number of passes per coverage of the F-4E is 8.58 passes per coverage for channelized traffic and 17 passes per coverage for non-channelized traffic (Reference 12).

b. C-141A Load Cart Traffic

Selected test items were subjected to simulated C-141 traffic. The C-141 employs a twin-tandem main gear; each incorporates two sets of dual wheels, positioned one behind the other, for a total of four wheels per main gear (Figure 7). The C-141 load cart, shown in Figure 8, applies a 141,000-pound main gear load at 185 pounds per square inch (psi) tire pressure. C-141 load cart traffic was applied over a 10-foot traffic lane in a normal distribution pattern (Figure 9) which achieved 3.6 passes of the aircraft per coverage. The reported ratio of passes per coverage of the C-141A is 3.44 passes for channelized traffic and 6.34 for non-channelized traffic (Reference 12).

6. DATA COLLECTION

a. Data collected for each test item generally included:

(1) Profiles at various levels of exposure to load cart traffic;

(2) California Bearing Ratio (CBR);

(3) Modulus of subgrade reaction;

(4) Wet and dry density readings; and

(5) Moisture content from various sections of the repair.

b. Appropriate laboratory test results pertaining to the differing surfacing materials were obtained and included in the various analyses. Profiles were taken with a self-leveling level and a survey rod; the accuracy tolerance was 0.01 foot. Test methods prescribed in applicable Air Force manuals and Military Standards (References 13, 14, and 15) were adhered to throughout the field testing program. Each test item was photographed; selected items were filmed during repair.

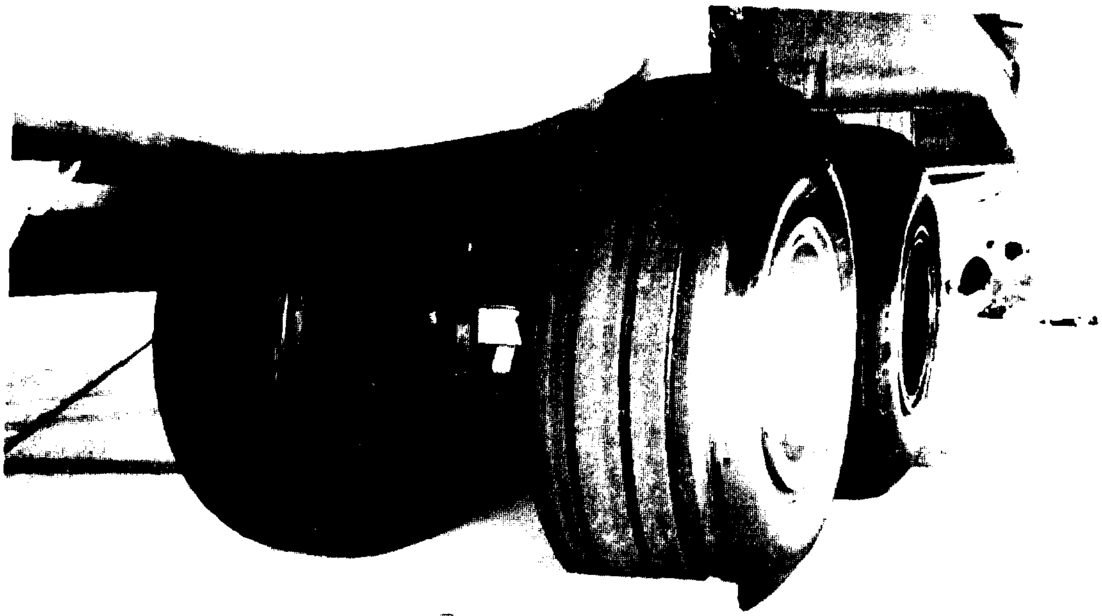


Figure 7. Twin Tandem C-141 Gear

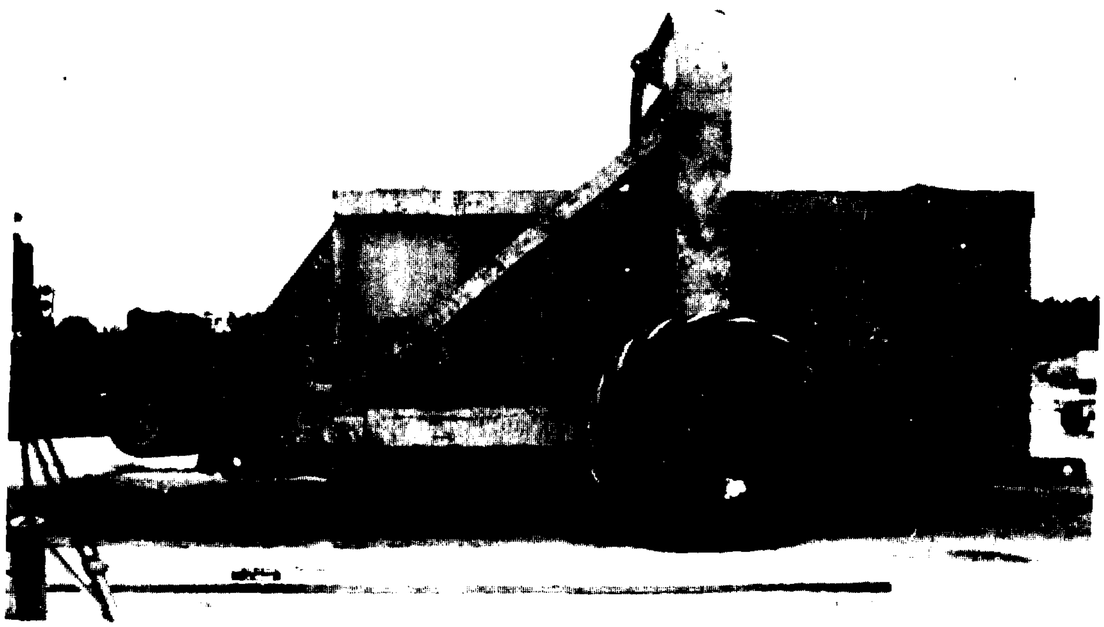


Figure 8. C-141 Load Cart

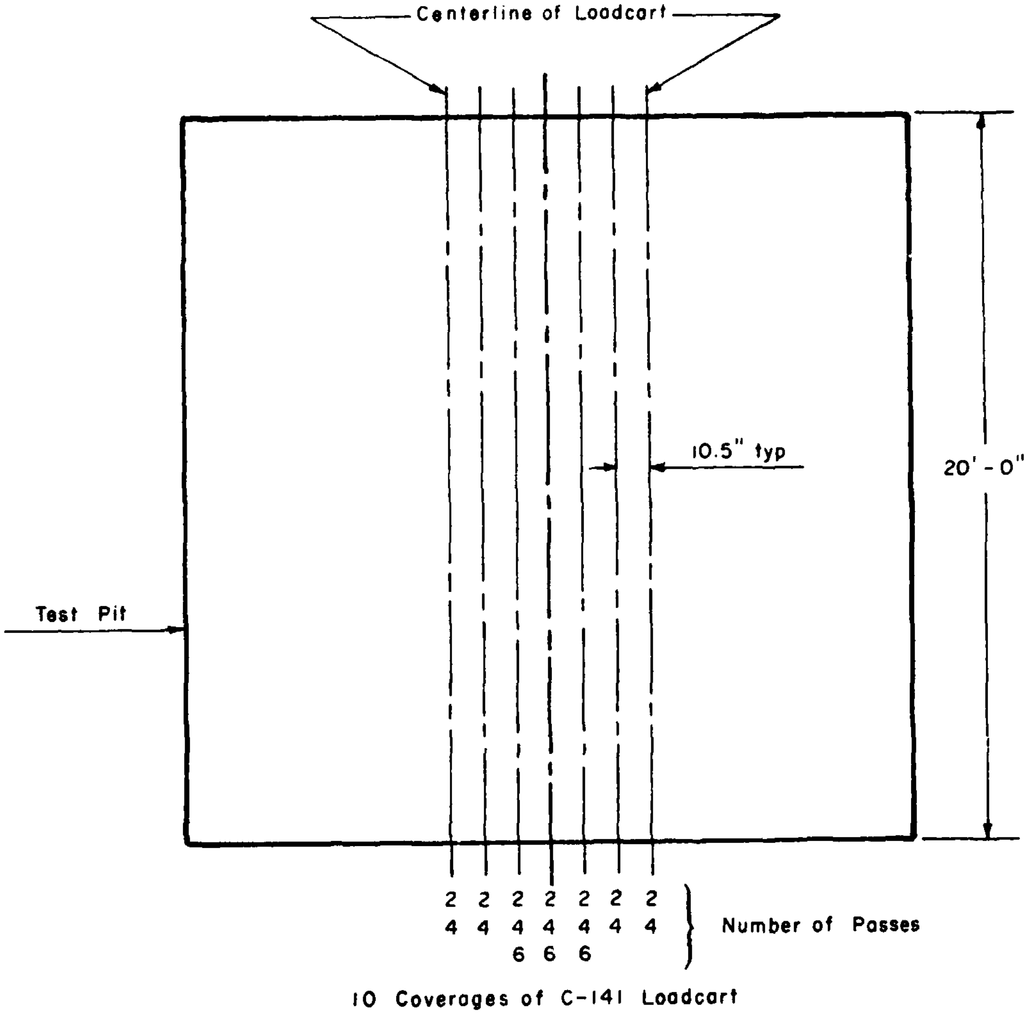


Figure 9. Traffic Distribution Pattern for the C-141 Load Cart

SECTION III

TEST CRITERIA

1. GENERAL

a. Definition

The word "expedient," when used in the context of runway repair during military operations, has been defined as "any paving or surfacing operation that must be completed quickly and whose end result is temporary in nature" (Reference 16). This is an adequate description of the task of rapidly repairing damaged airfield pavements. Any repair done rapidly, hence an expedient repair, implies that the result is only temporary, will require maintenance, and will have to be replaced or upgraded relatively soon after placement.

b. Delineation of Runway Repair Responsibility

A Joint Contingency Construction Requirements Study (JCCRS) Action Memorandum, dated January 27, 1978, and signed by the respective secretaries of the Army and the Air Force (Reference 17), assigns expedient repairs to the Air Force while holding the Army responsible for permanent repairs and any expedient repairs which exceed the organic capability of the Air Force.

2. TRAFFIC AND REPAIR LEVELS

a. F-4

Specific F-4 and C-141 traffic data did not become available to AFESC until field testing documented by this report was nearly completed. Consequently, the failure criteria and acceptable number of F-4 coverages remained the same as in the preceding field test (test items 1 through 15, Reference 6): 12 coverages as the minimum acceptable and 150 coverages as the maximum required repair capacity. Assuming a 70-inch wander distance and a theoretical normal distribution of channelized traffic, this gives a pass-to-coverage ratio of 8.58 (Reference 12). This translates into a minimum acceptable repair capacity of 103 passes of an F-4E and 1287 passes of an F-4E as maximum required repair capacity for these field tests. Time constraints did not allow each repair to be subjected to the maximum number of coverages of fighter traffic that will be expected; however, 150 coverages from earlier tests have shown this to be an adequate level where additional traffic shows no further deterioration for crushed limestone tests.

b. C-141

To accommodate the addition of C-141 aircraft, 20 coverages of the C-141 were assumed as the minimum acceptable level of traffic. Assuming channelized traffic, this produces a ratio of 3.6 passes per coverage (versus 3.44, shown as a theorized normal distribution in Table 4 of Reference 12).

c. Calculated Traffic Levels

Both the C-141 and F-4 traffic levels were arbitrarily picked to give a fair indication of the trafficability of a repair item while minimizing load cart trafficking time.

3. FAILURE CRITERIA

a. General

The failure criteria of test items for expedient repairs are very difficult to establish. Although a section may crack and show signs of overstressing, it may still be functional for emergency operations. Table 3 summarizes the failure criteria used by the U.S. Army Corps of Engineers in past accelerated traffic field tests (Reference 18).

TABLE 3. U.S. ARMY CORPS OF ENGINEERS FAILURE CRITERIA

Surface	Criteria
Flexible	1-inch deformation and rutting 0.25-inch deflection Severe cracking, surface no longer waterproof
Rigid	Initial failure: First crack *Shattered slab:* Slab cracked into 6 pieces Complete failure: Slab cracked into 35 pieces
Unsurfaced	3-inch deformation and rutting 1.5-inch deflection
Landing mat	20 percent of panels showing breakage

These criteria are not directly applicable to the problem of expedient patches. Long after a patch has failed by engineering or conventional pavement standards, it may remain usable for emergency operations. Possible failure criteria will be discussed individually.

b. Deformation and Rutting

Permanent deformation and rutting are evidence of consolidation and shear deformation of material under traffic. Reference 19 defines rutting and depressions on airfield surfaces as light for depths of 0.25 to 0.50 inch, medium for 0.50 to 1 inch, and high for over 1 inch. Existing unsurfaced soil criteria allow ruts up to 3 inches deep, but this is based on tests with cargo aircraft which may not be applicable to tactical aircraft. The C-130 aircraft has successfully operated during takeoff with ruts of 3 to 6 inches and landed with ruts of 4 to 8 inches (Reference 20). A C-141 successfully operated with ruts up to 4.5 inches (Reference 21). Operation with tactical aircraft on unsurfaced surfaces appears to be limited to a test of an F-5 on a high CBR subgrade with negligible rutting (Reference 22). There is no evidence that the 3-inch rut criterion for unsurfaced soil

is acceptable for tactical aircraft though it appears to be conservative for cargo-type aircraft. Lacking any better criteria, this study will use the conventional criteria of a 1-inch permanent deformation in a paved test item and a 3-inch rut (measured from top to bottom of the wheel depression) for unsurfaced soil materials.

c. Deflections

Deflections are limited to 0.25 to 1.5 inches for paved and unsurfaced areas in Table 3. Generally, deflection limits are based on empirical correlations of excessive deflections with predefined failure criteria (Reference 23) and are not cause for functional failure by themselves. The subgrade accounts for 70 to 95 percent of the surface deflection which can be limited by reducing subgrade stress through thicker or more rigid pavements (Reference 23). The resilient, or recoverable, deflection of a subgrade is strongly influenced by soil type, number of stress cycles, aging before stress loading, stress intensity, compaction methods, density, and moisture content (Reference 24). The clay subgrade for these tests has relatively low density and high moisture content and is subjected to relatively few repetitions of high stress. This condition is thought to be representative of the subgrade condition of craters backfilled with clay debris. Resilient deflections can be expected to be large under these conditions. However, since deflection is not a functional failure in itself, no deflection failure criteria will be used for this study.

d. Cracking

Cracking in a pavement structure is evidence that the material has been overstressed. This may be due to either load or environmental conditions. Cracking may result in increased water infiltration with consequent weakening of the subgrade, in spalling and surface deterioration, and in increased roughness. In this test, formation of tight cracks will not be considered failure until surface deterioration occurs which would impede aircraft operation. This is a subjective evaluation.

e. Differential Elevations at the Joint

Under traffic the repair patch is likely to settle so that there is a differential elevation at the joint between the pavement and repair. This may result in damage to aircraft structure and tires and increased roughness. Reference 19 defines high severity faulting for runways and taxiways as a difference in elevation of 0.5 inch; for aprons this is increased to 1.0 inch. Computer simulation studies (presently unvalidated by field tests) also indicate a potential roughness problem with tactical aircraft when they must traverse several 1.5-inch elevation changes (References 2 and 3). This test uses 1.0-inch differential elevation between the repair and original pavement as the failure criterion.

f. Foreign Object Damage

Spalling, raveling, and scaling are forms of surface distress which offer potential foreign object damage (FOD) by ingestion of particles

in jet aircraft engines. No criteria have been developed in this area to determine acceptable levels or actual seriousness of the potential FOD problem.

g. Maintenance

Maintenance may keep a repair usable long after it has originally failed. In the past, only tests with landing mat have taken possible maintenance into account. The Corps of Engineers has assumed that 10 percent of the landing mat in a test section may be replaced for maintenance, and failure occurs after another 10 percent of the panels fail. This gives the 20-percent failure criterion given in Table 3. Although maintenance will be a part of expedient repair, it is not clear how to take this into account in the testing, and no maintenance criterion will be included in this testing.

h. Test Failure Criteria

Table 4 summarizes the failure criteria used for this testing. Improved failure criteria need to be developed, but the criteria given in Table 4 provide a point where aircraft operation can be considered hazardous.

TABLE 4. TEST FAILURE CRITERIA

Failure Mode	Paved Test Item	Unsurfaced Test Item
Permanent Deformation and Rutting	1 inch	3 inches
Deflection	None used in this study	
Cracking	Open cracks leading to surface deterioration judged to affect aircraft operations	Not applicable
Differential Elevation Between Repair and Pavement	1 inch	1 inch
FOD	Subjective	Subjective

SECTION IV

TEST RESULTS

1. ORGANIZATION OF DATA

a. General

This section describes the results of field testing conducted during the period July 1978 through September 1979. While this report is complete within itself with respect to test items 16 through 35, the reader is encouraged to review the report covering test items 1 through 15 (Reference 6).

b. Chronology and Numbering of Test Items

Chronological numbering indicates its order in the overall Phase 2 field test sequence. For the sake of better readability and comparison of test results, test items in this section are presented generically. Test items, grouped within each of the three general categories of expedient repair materials and designs, are:

(1) Polymer concrete - test items 16, 18, 33, 35;

(2) Crushed limestone - test items 19, 22, 21, 24, 25, 26, 27 and 28, 32;

(3) Foreign object damage (FOD) covers - test items 20*, 23, 31, 34, 29, 30.

*NOTE: Item 17 was redesignated item 20.

2. POLYMER CONCRETE

Polymer concrete was used in the design of four structural cap systems. Variations in polymer concrete formulations, cap thickness, base course composition, and mixing methods were employed to meet the objectives of the test items described below:

a. Item 16 - 7 Inches of Methyl Methacrylate Polymer Concrete

(1) Objective. The objective of this test was to determine the feasibility of rapidly field mixing a 7-inch methyl methacrylate (MMA) polymer concrete structural cap capable of supporting 150 coverages of the F-4 load cart.

(2) Approach. Although laboratory investigations and small scale field tests had been conducted using MMA polymer concrete with some success, no previous attempt had been made to rapidly mix a 400-square-foot area in the field. Consequently, it was decided to precede field testing with expanded laboratory tests to determine the flexural strengths of different formulations of MMA polymer concrete.

(a) Laboratory Tests. These tests were designed to establish the effects of varying factors on the flexural strength of MMA polymer concrete. Pertinent results, which formed the basis for subsequent field test of item 16, are summarized below:

1. The best results for flexural strength were obtained with the following chemical mixture:

Monomer	90%	MMA
	10%	Trimethylolpropane Trimethylacrylate (TMPTMA)
Initiator	1%	Benzoyl Peroxide
	0.5%	N,N-dimethyl-p-toluidine (DMPT)

2. A mixture of MMA polymer concrete and a composition of 80-percent base course and 20-percent beach sand produced a polymer concrete with the highest flexural strength. At 75°F, the flexural strength was approximately 1000 psi. A higher percentage of beach sand would increase the flexural strength, but the work involved in removing impurities would make it impractical to use beach sand in large quantities. Due to the problem of processing large quantities of dry beach sand, three other dry sands from the local asphalt company were tested.

3. The polymer formulation yielded a pot life of approximately 10 to 15 minutes and a cure time of 25 to 30 minutes with a peak exotherm of 130°F.

(b) Field Test

1. Field Mixing System. To meet the objective, a simple field mixing system was designed to dispense eight 55-gallon barrels of MMA within 10 minutes. The system, comprised of standard 2-inch galvanized pipe leading from two drums into a single tee connector, was coupled to a 2 1/2-inch Kenics Static-Mixer 3 feet long (Figure 10). Three-quarter-inch pipes were used to permit the barrels to be completely vented while positioned on their sides. Two quick-opening valves were employed to simultaneously allow equal volumes of MMA to feed by gravity into the Static-Mixer from each barrel. Unrestricted, this system was capable of emptying both barrels in 1 3/4 minutes.

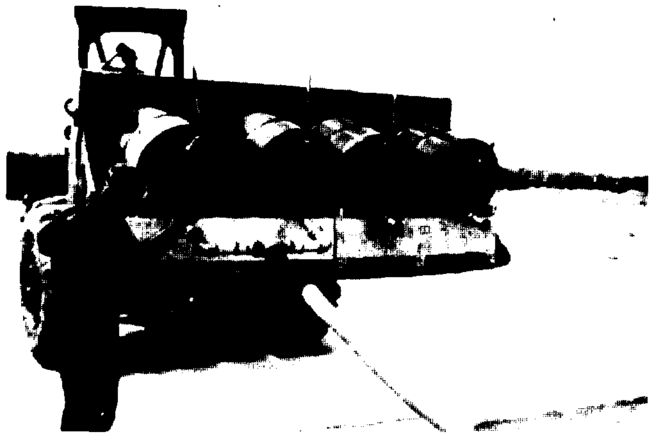


Figure 10. Field Mixing System

2. Test Pit Construction. The test pit was constructed with clay at 7 inches from the surface, compacted and maintained at the proper moisture content to reach a CBR of 4 to 7. Due to the slow saturation of well-graded aggregate with MMA, it was decided to construct the polymer concrete cap in two lifts of approximately equal thickness. The aggregate selected, a mixture of crushed limestone and dried sand from a local asphalt company, was thoroughly mixed and the first lift placed into the test pit.

3. Procedures. Four drums of methyl methacrylate were prepared the day before with promoter added and four were prepared immediately prior to the test with initiator added. TMPTMA, crosslinking agent, was also added equally to both sets of barrels. Two crews then proceeded to empty four barrels of polymer liquid into the test pit (Figure 11). The hoses used to dispense the liquid in the repair restricted the flow of the liquid. Allowing 5 to 8 minutes to empty the barrels, however, was helpful because it reduced washing away of the aggregate. The repair was then rodded to ensure complete saturation of the aggregate. A front-end loader added aggregate and leveled the repair with the surrounding concrete. Meanwhile, the mixing systems were being connected to four additional barrels of prepared MMA liquid. The second lift of aggregate was then saturated with liquid and rodded again. Sand was added to the surface to achieve a smooth surface during screeding. However, screeding was to be accomplished by a hand-held screed which proved to be inadequate. The repair, therefore, was not screeded. A polyethylene cover was used to minimize evaporation losses of MMA.

4. Results. The polymer concrete reached a peak exotherm temperature of 176°F after 20 minutes. After 2 hours, when the polymer concrete had cooled to only 130°F, load cart traffic was initiated.

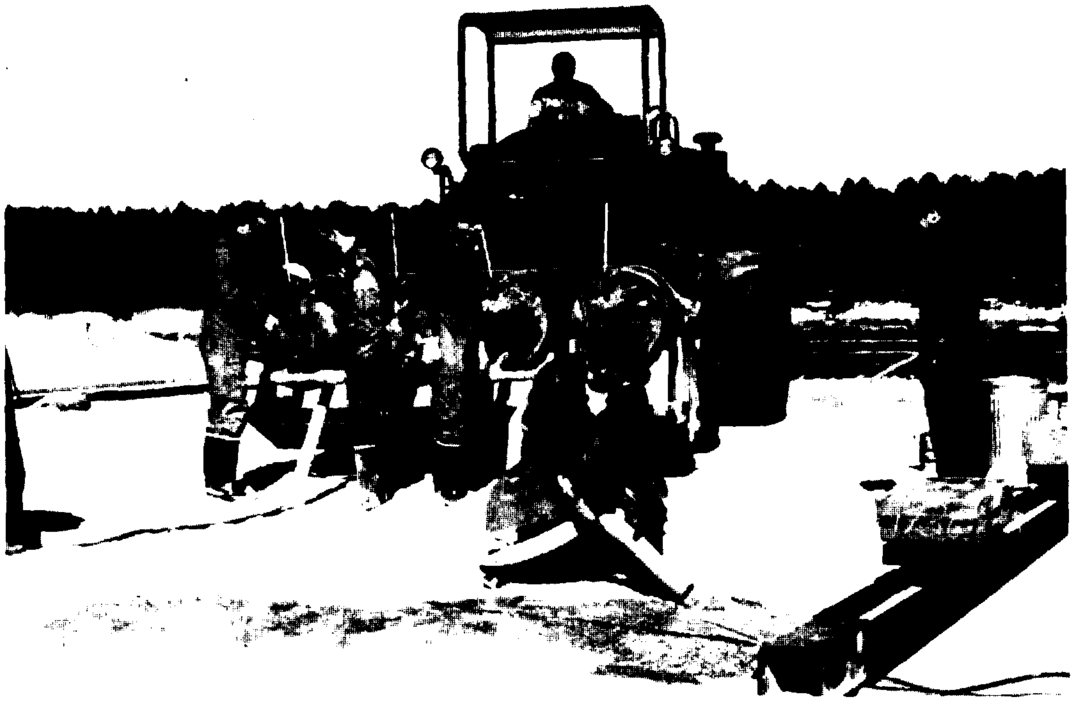


Figure 11. Application of Polymer Liquid, Test Item 16

The repair easily withstood 150 coverages of the F-4 load cart. Core samples of the test surface achieved tensile splitting strengths of 297, 492, and 762 psi. Figure 12 shows the results of profiles taken from the surface of the test pit. Deformation of approximately 1 inch indicates the subgrade had consolidated and the bond between the polymer concrete and the existing concrete did not hold. The MMA polymer concrete proved capable of supporting F-4 traffic without excessive repairs. Deformation occurred as a result of the densification of the subgrade and the lack of sufficient bonding between the polymer concrete and the adjacent concrete. The edges of the concrete pit required a clean surface before adequate bonding could occur.

b. Item 18 - MMA Polymer Concrete with Drycrete

(1) Objective. The objective of this test was to determine if a pavement thinner than item 16 could withstand the F-4 loading and determine the feasibility of using a prepackaged concrete mix (Drycrete) as an alternate source of dry aggregate.

(2) Laboratory Test. Laboratory tests were conducted with 6x6x18-inch beams which concluded that if mixed with 25-percent pea gravel, a prepackaged concrete mix could be easily wetted and saturated with MMA by using a standard concrete finger-type vibrator. Test beams also showed flexural strengths in excess of 1200 psi in 1 hour.

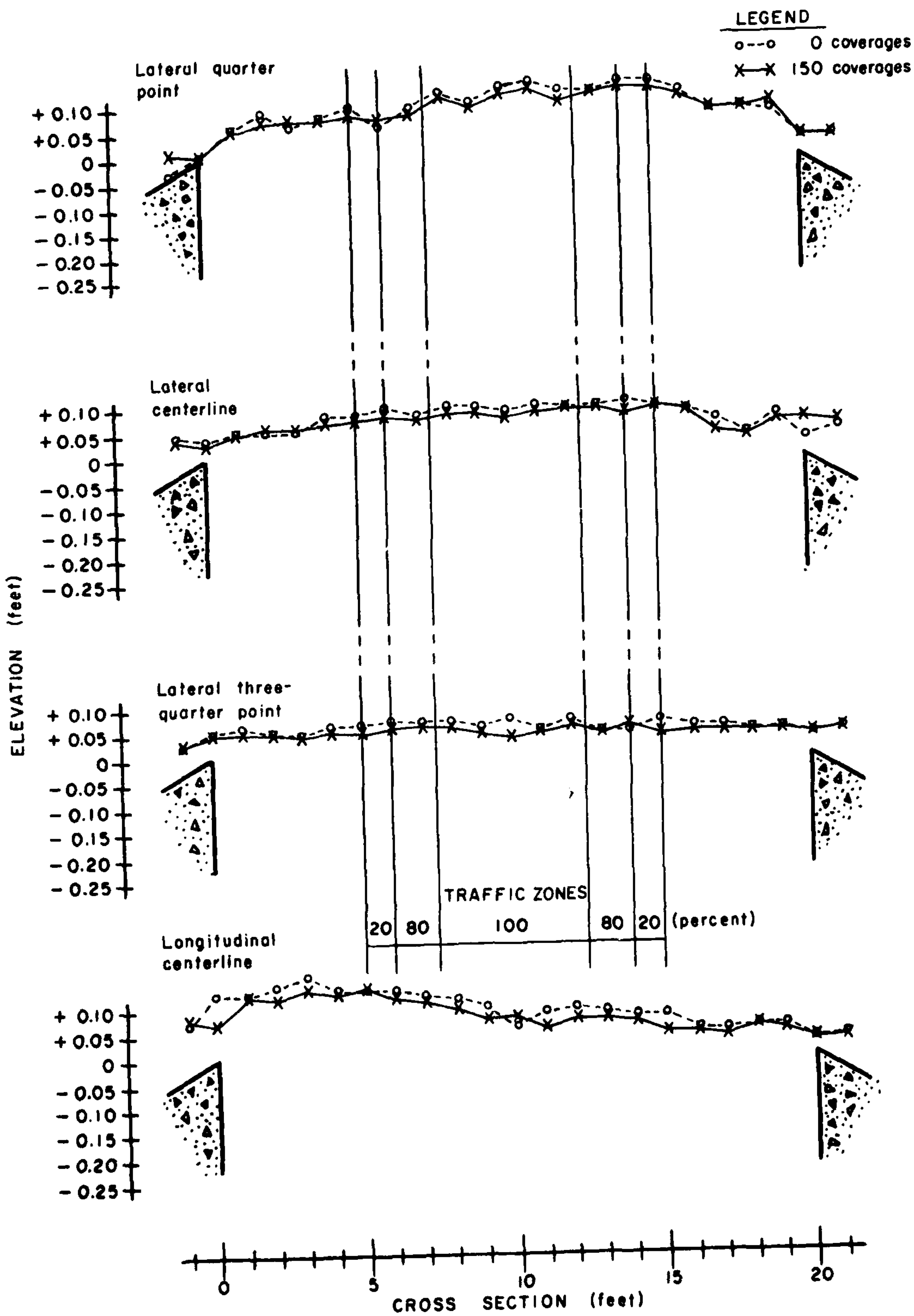


Figure 12. Surface Profiles, Item 16

(3) Field Test

(a) Test Pit Construction. A 20-foot by 20-foot test crater was constructed in three 6.5-foot-wide sections, at depths of 3, 4, and 5 inches. The clay subgrade was prepared in the standard manner to achieve a CBR of 4 to 7. Drycrete, a commercial prepackaged concrete mix in 60-pound bags, was dumped onto the concrete adjacent to the crater with 25-percent pea gravel (Figure 13).

Figure 13. Preparation of Drycrete and Pea Gravel Prior to Mixing, Test Item 18

The concrete mix and pea gravel were mixed with a small dozer and then placed into the test crater in a single lift. At this point it was discovered that insufficient pea gravel was on hand. The test item was then filled by adding all concrete mix to bring the surface level even with the adjacent concrete.

(b) Procedure. A large screed was constructed from a 14-inch I-beam and placed into position to be dragged across the surface by a front-end loader. Six drums of methyl methacrylate were prepared as in test item 16 with the following slower curing formulation:

Monomer: 93% MMA; 7% TMPTMA

Initiator: 1% Benzoyl Peroxide; 0.33% DMPT

(c) Results. As in test item 16, two crews dispensed the MMA liquid onto the aggregate using the same gravity feed-mixing system.

However, when an attempt was made to saturate the aggregate by vibrating the aggregate liquid mixture, it would not mix. Attempts to mix the aggregate and liquid by vibrating, rodding, and hoeing using a mortar hoe proved unsuccessful due to the high cement content. The hoe was the most successful, although it appeared to only allow the liquid to penetrate approximately 1 inch. After 30 minutes, the polymer concrete began to harden and was therefore screeded. The screed worked perfectly but, as explained below, the repair was a failure. After 1 hour, the polymer concrete hardened and it was decided to traffic the repair even though inspection revealed soft spots. The initial trafficking in the center of the repair failed after six coverages by completely cracking the thin pavement and shear failure of the subgrade. The inspection of concrete in the failed area revealed that the polymer had only penetrated the aggregate approximately 1 inch. It was decided to place additional load cart traffic in an area which appeared to be more sound. This area was subjected to 142 passes of the load cart in a single wheel path before failure. The test item did not pass the failure criteria. There was loose gravel on the surface and insufficient penetration of the monomer was evident (Figure 14).

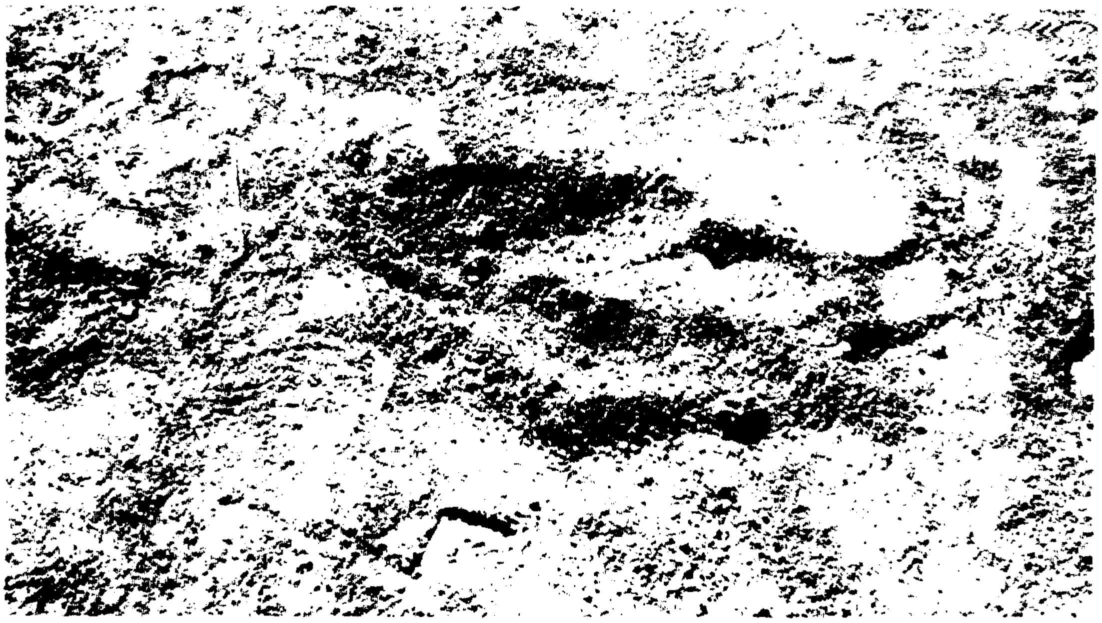


Figure 14. Surface of Test Item 18 After 142 Passes of the F-4 Load Cart

c. Item 33 - Transit Mix Silikal®

(1) Objective. The objective of this test was to determine the feasibility of using a conventional transit mix truck to rapidly mix polymer concrete to be used in crater repair and to subject the structural cap to F-4 load cart traffic.

(2) Background. Silikal® is manufactured in the United States by Silikal North America, Inc. (see List of Manufacturers, Appendix B). Until this time, Silikal® polymer concrete had not been mixed in a transit mix truck in the United States, and representatives of the company were invited to attend the field test. The Silikal® R-17 polymer concrete mix used in this test was composed of the R-17 powder, shipped in 55-gallon fiber drums, and the R-17 liquid (MMA) contained in 55-gallon metal drums. The combination of powder and liquid mixed together with an aggregate forms a strong, fast-curing polymer concrete capable of supporting heavy loads.

(3) Test Pit Construction. The test pit was filled with clay to a height of 4.5 inches below the surface of the concrete surrounding the pit. The pit was partitioned into halves to facilitate two separate pours.

(4) Procedures. A concrete bucket was used to load the aggregate and R-17 powder into the transit mix truck (Figure 15).

Figure 15. Loading of Aggregate and R-17 Power into Transit Mix Truck, Test Item 33

In both mixes, the R-17 powder was dry-mixed with the pea gravel for 2 minutes and then mixed for 30 seconds after the R-17 liquid had been added Addition of R-17 liquid is shown in Figure 16.

Figure 16. Addition of R-17 Liquid, Test Item 3b

Initially, the polymer concrete discharged from the transit mix truck quite easily--very fluid and workable, with very low slump. Within 3 minutes, the polymer concrete already began to harden showed almost no slump, and had to be assisted from the chute. Despite immediate efforts to flush the drum of the truck, some hardening occurred.

(5) Results. In the first pour, the temperature of the polymer concrete peaked at 145°F about 30 minutes after mixing. The second pour peaked at 150°F after 35 minutes. Screeding was problematic since the polymer concrete hardened too quickly, leaving a rough and uneven surface.

After ten coverages with the F-4 load cart, a crack developed along the cold joint between the two sections in the center of the pit. Repairs were made to smooth out the surface and fill in the depression previously caused by the screed beam where some deflection was observed during passes of the load cart. Nine bags of R-7 mix (a surface repair mix) and three bags of R-17 mix were used to make the repairs. After 20 coverages, another crack developed along the cold joint and a small amount of flexing was detected. After 40 coverages, a few hairline cracks developed with some cracks along the edge of the pit and the flexing became more noticeable. A shear deformation failure occurred on the 74th coverage when the wheel fell through the surface (Figure 17).

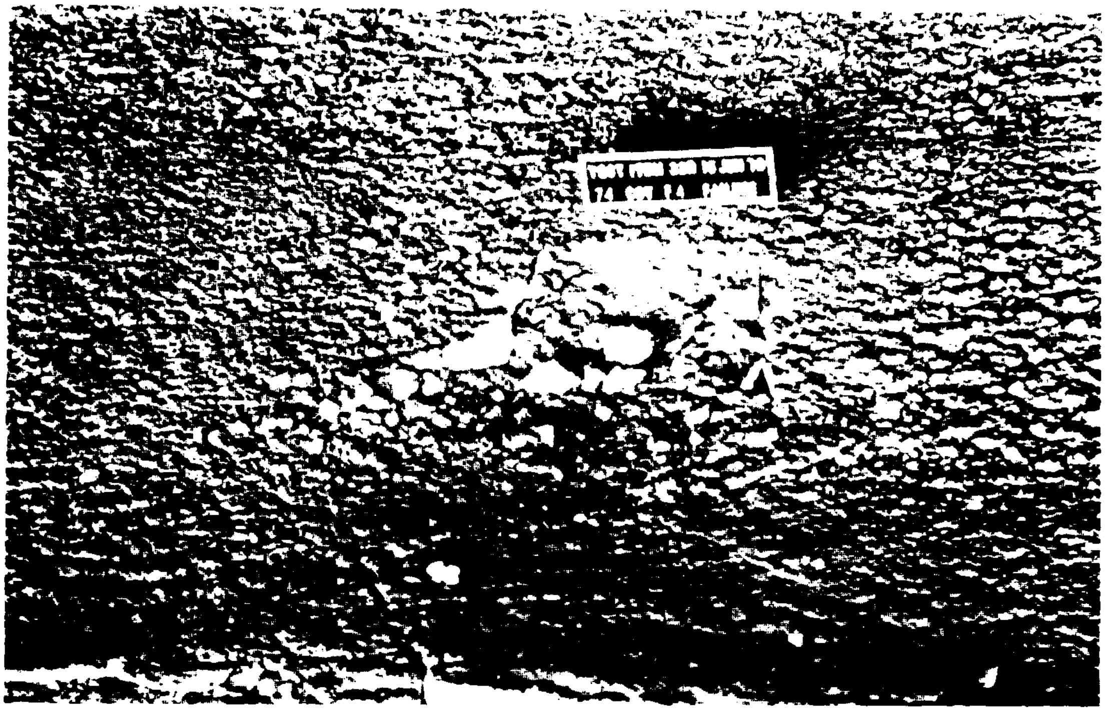


Figure 17. Shear Failure of Test Item 33 After 74 Coverages

Profiles were taken of the test surface (Figure 18); complete core samples could not be taken in the traffic lane of the first pour due to internal cracks. These cracks caused the flexing that was noted during the coverages.

d. Item 35 - Silikal® Polymer Concrete, Hand Mixed

(1) Objective. Item 35 was designed to test the structural integrity of Silikal® polymer concrete poured over 8 inches of 2-inch sized aggregate and to determine the feasibility of field-mixing, by hand or in small mixers, a quantity of Silikal® sufficient to repair a small crater.

(2) Test Pit. For the test, 500 30-pound bags of Silikal® R-17 powder and 150 1/2-gallon containers of Silikal® R-17 liquid monomer were prepositioned beside the test pit with additional supplies located nearby. The aggregate was loosely placed over a clay subgrade to a depth of 8 inches below the surface of the surrounding concrete. Polymer concrete was poured in 2- by 20-foot sections to allow time for screeding between successive pours.

(3) Procedures. Two portable mixers of 2.5 cubic feet capacity each were used. After pouring one section using the portable mixers, the crew preferred to complete the test by hand. Each bag of powder was poured into the plastic bag, provided in each bag of mix, along with a half gallon

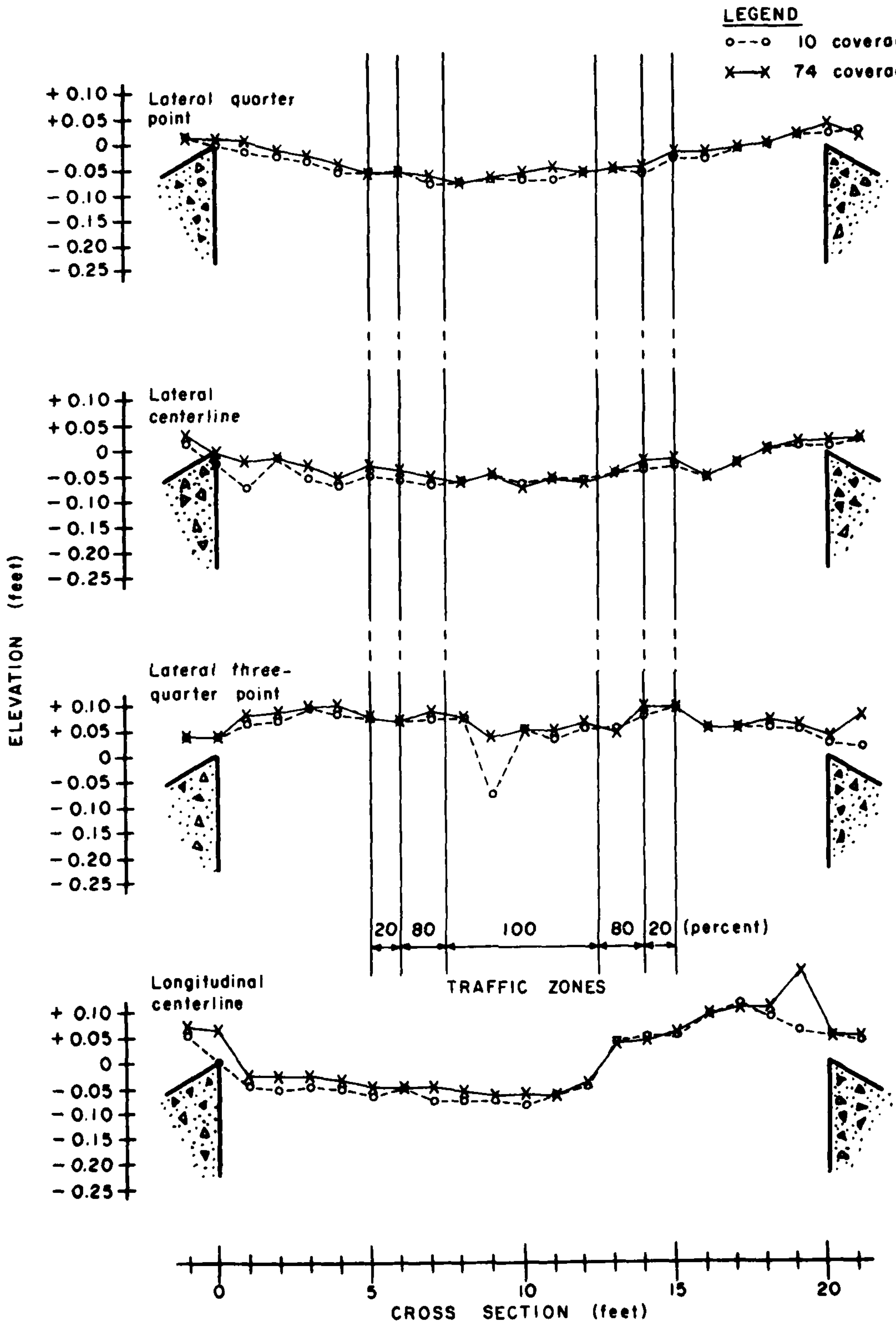


Figure 18. Surface Profiles, Item 33

of liquid monomer and then mixed for approximately 30 seconds. The contents were then poured over the aggregate (Figure 19).

Figure 19. Mixing and Pouring Polymer Concrete, Test Item 35

Six men performed the mixing and pouring, while six to eight others supplied materials or screeded the surface after each section had been poured. The mix appeared to be penetrating the aggregate sufficiently. An earlier trial pour had shown about 2 inches of mix at the top and bottom of the aggregate with a void in between. It took approximately 1 hour and 45 minutes to complete the test pour using 461 bags of polymer concrete. The surface was smooth with the exception of some holes where the mix ran down through the aggregate and which had not been patched with additional mix. The ambient temperature was approximately 90°F with high humidity. Rubber gloves, eye goggles, and masks were provided for the work crew; they declined the respirator masks. There were no ill side effects reported by the crew from working with the monomer. Fire extinguishers were on the site in case a fire developed due to the electric mixer igniting the liquid monomer.

(4) Results. F-4 load cart traffic commenced 2 hours after the last bag was mixed. A very slight amount of deflection occurred at the initial drop-off at the center of the traffic lane, and after 60 coverages, the test item had lost its bond to the existing concrete along the edges of the traffic lane. A crack developed across an area where a large spall was repaired in conjunction with the pour. The clay subgrade appeared to be consolidating.

After 100 coverages, a small amount of spalling had occurred where the test item joined the adjacent concrete and a few hairline cracks were running parallel to the traffic lane. The flexing appeared to be increasing.

After 150 coverages of the load cart, the flexing had increased and a larger spall developed where the test pit met the concrete lip in the traffic lane (Figure 20).

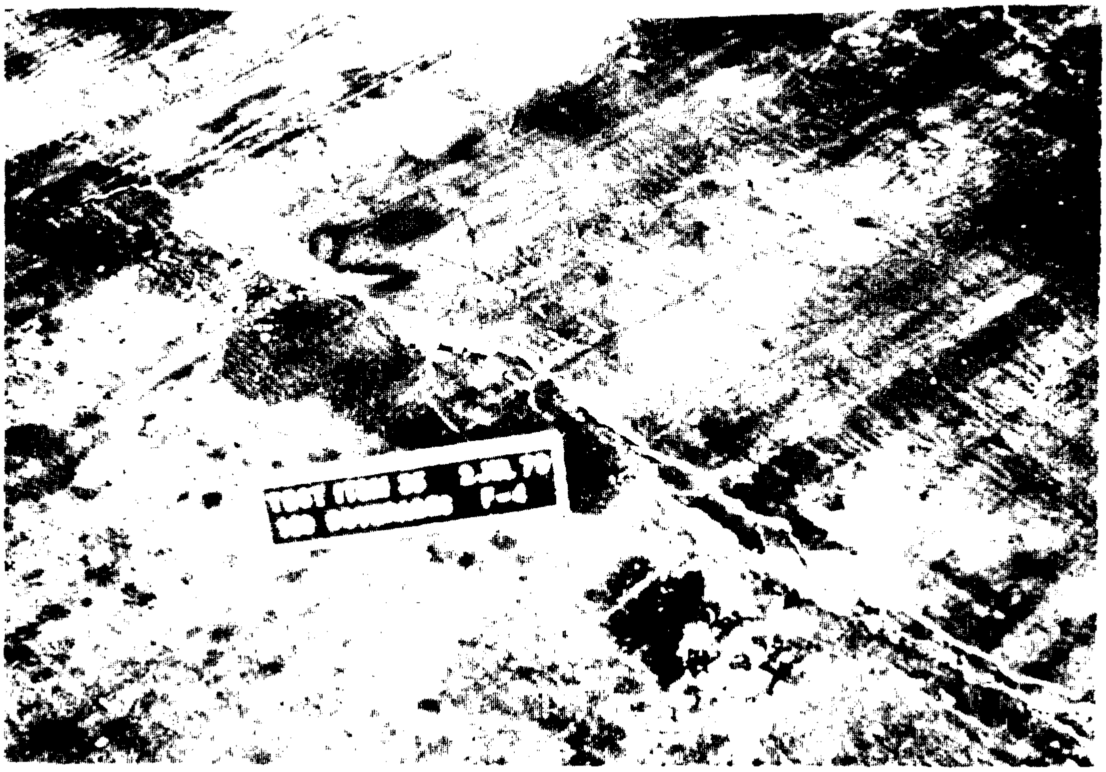


Figure 20. Test Item 35 After 150 Coverages with the F-4 Load Cart

Profiles obtained at this point are shown in Figure 21.

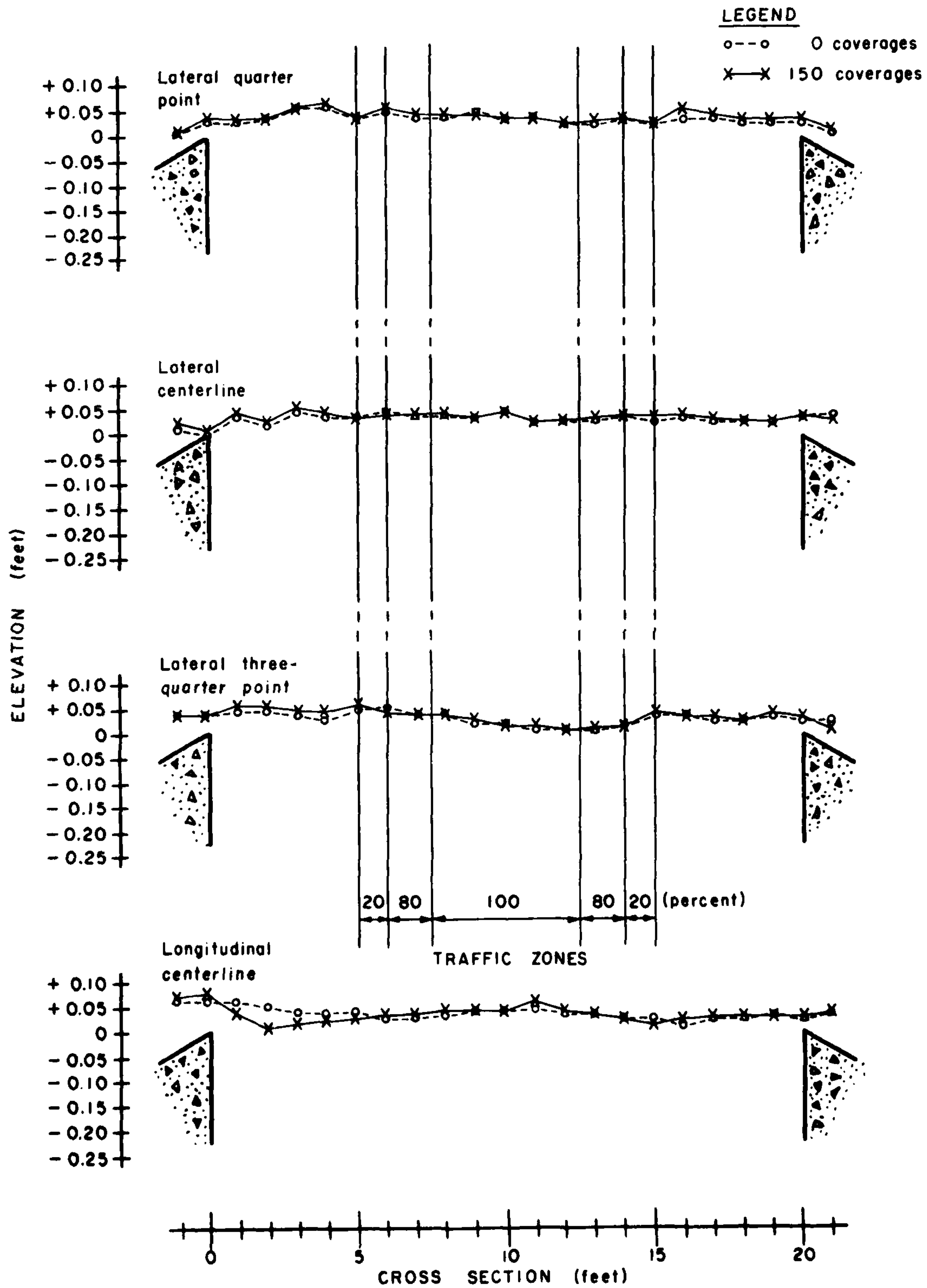


Figure 21. Surface Profiles, Item 35

Flexing was severe enough to rule out C-141 traffic over the test pit. Core samples were taken and found to have monomer at the top and bottom with aggregate in between (Figure 22).

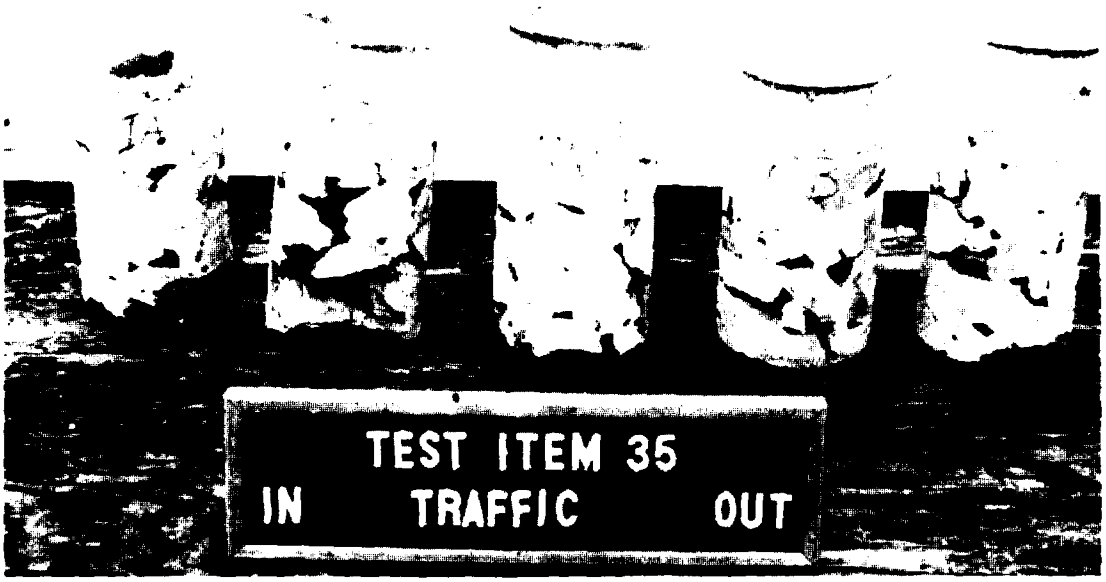


Figure 22. *Core Samples*

This condition resulted in a lack of bonding and flexing when the load cart passed over the polymer concrete.

e. Summary of Polymer Concrete Test Results

Tests conducted using polymer concrete for the design of the structural cap system produced two successful items (16, 35) and two failures (18, 33). The failures in both cases resulted from improper application and were not attributable to the material itself. While the results of these four tests showed promise for the use of polymer concrete as a structural cap, they also pointed out the inadequacy of application methods. Hand mixing was considered too slow for craters greater than 5 to 10 feet, and transit mix truck operation was impractical due to time-consuming loading in the field.

3. CRUSHED LIMESTONE

a. Approach

Nine tests were conducted to evaluate the performance of graded crushed limestone as an unsurfaced base course aggregate for rapid runway repair. The 24-inch lift of limestone used in each of these tests was placed in test pits at moisture contents ranging from 2.0 to 5.6 percent.

After compaction with a vibratory roller (RayGo 400A or 510A), the individual test item was subjected to load cart trafficking.

b. Soils

(1) Limestone. The 1 1/2-inch-minus crushed limestone used in these tests showed the following characteristics:

Gradation: (Figure 23)
Specific Gravity: 2.76
Liquid Limit: Non-plastic
Plasticity Index: Non-plastic
Unified Soil Classification: SP-SM
Maximum Dry Density (Modified AASHTO): 147.2 pcf
Optimum Moisture Content: 5.7 percent

(2) Clay. Clay used for the test subgrade is described in Section II, paragraph 3.

(3) Moisture Content. In all following discussions, the moisture content of a test item is defined as the moisture content at the beginning of the test.

c. Item 19 - 24 Inches of Crushed Limestone, RayGo 510A, 5-Percent Moisture

(1) Objective. The objective of this test was to determine the suitability of crushed limestone as an expedient runway repair material during inclement weather conditions. As an ancillary objective, the test sought to establish the compaction capability of the RayGo 510A vibratory compactor.

(2) Procedure. Prior to placement, 300 gallons of water were added to the limestone to obtain a moisture content of 5 percent. This percentage was calculated to represent the limestone's moisture content when exposed to precipitation during all-weather repair operations. An additional 50 gallons of water were added when moisture tares showed that the test material was still too dry. After thoroughly mixing, the limestone was placed with a front-end loader, overfilling the test pit to a level 6 inches above the surface of the surrounding concrete. Four coverages of the RayCo 510A using a vibration setting of 1500 vpm compacted the limestone to 1 inch below the adjoining concrete. More limestone was then added to overfill the pit by 1 inch. The test material was graded before compaction resumed. Since a dozer was not used to place the materials into the test pit, this test started at a lower pounds per cubic foot (pcf) density (0 coverages, Table 5) than those achieved during the compaction study (Reference 24). After 14 coverages, a 5.3-percent moisture content and 145 pcf dry density reading were taken from the center of the pit. A total of 32 coverages were made with the RayCo 510A. Moisture and density readings taken of the base course at 4-, 8-, and 12-inch depths are recorded in Table 5.

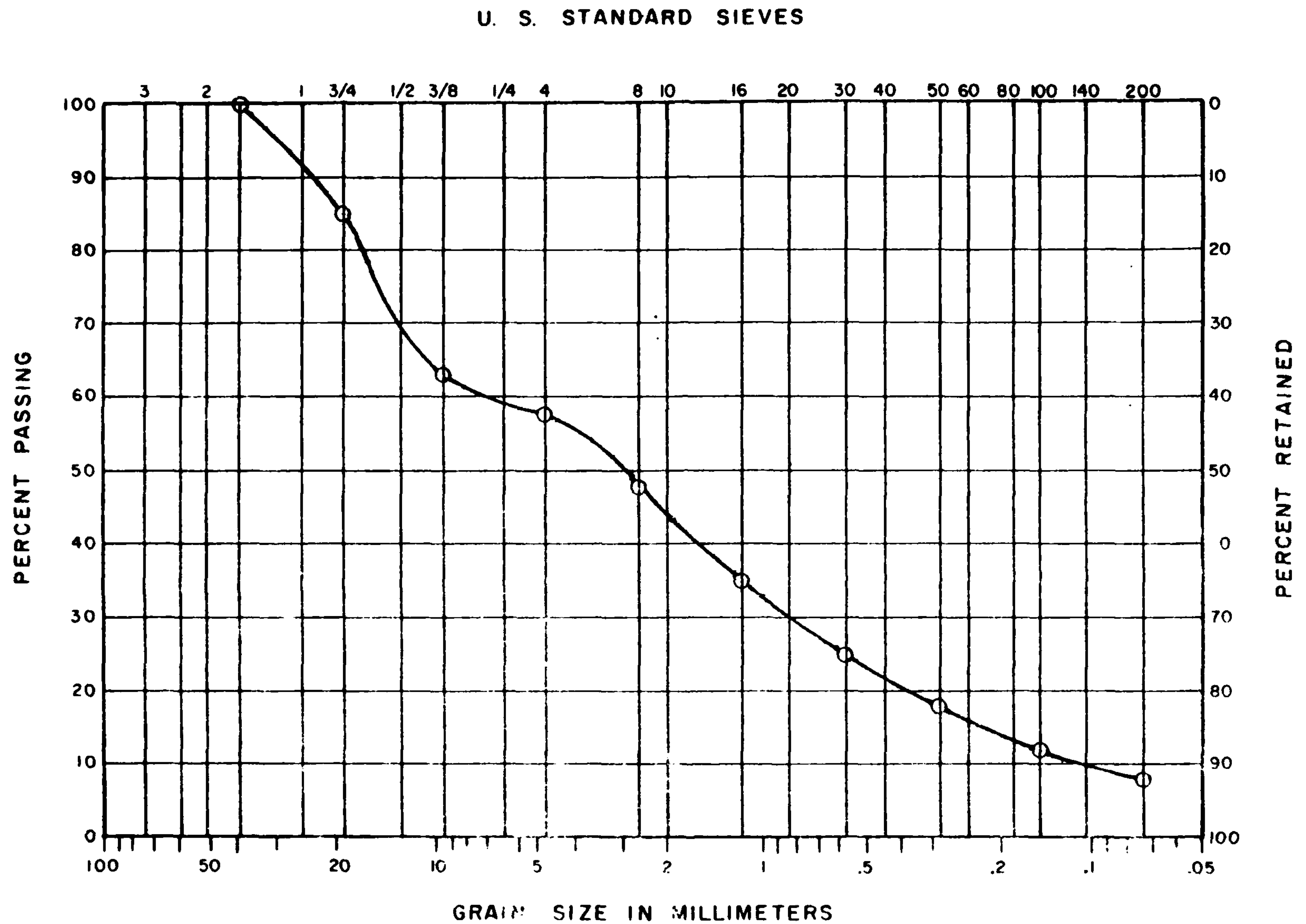


Figure 23. Gradation of 1 1/2 Inch - Crushed Limestone

TABLE 5. MEASUREMENTS, TEST ITEM 19, 24 INCHES OF 1.5-INCH CRUSHED LIMESTONE BASE COURSE, UNSURFACED

RAYGO 510A COVERAGES	DEPTH (in.)	WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)
0	4 8 12	132.5 130.3 128.6	126.3 123.9 122.1	4.9 5.2 5.3
4	4 8 12	142.4 143.2 143.0	135.8 136.9 136.9	4.9 4.6 4.5
8	4 8 12	145.7 147.6 146.2	139.6 141.2 140.3	4.4 4.5 4.2
12	4 8 12	146.0 147.0 149.7	139.0 139.7 142.7	5.1 5.3 4.9
16	4 8 12	147.7 149.7 149.8	140.3 142.1 142.8	5.3 5.4 5.1
20	4 8 12	149.1 150.2 150.1	141.9 143.0 143.9	5.1 5.1 5.0
24	4 8 12	149.8 150.5 151.0	142.6 143.4 143.8	5.0 5.0 5.1
28	4 8 12	151.6 152.1 153.0	145.0 145.3 146.2	4.5 4.6 4.7
32	4 8 12	151.7 152.3 152.7	145.2 145.9 145.9	4.5 4.4 4.7
32	26 28	124.3 123.7	97.6 94.9	27.3 30.4

(3) Results. During the first coverage of the F-4 load cart, surface flooding was observed and a pumping effect occurred as the load cart passed over the surface. The surface showed ruts of approximately 0.75 inch, and crushed limestone tended to be pushed out of the test pit. After 20 coverages, consolidation of 2.4 inches was measured in the traffic lane (Figure 24). Traffic was halted, and density readings were obtained.

Figure 24. Surface Condition After 20 Coverages of the F-4 Load Cart

Prior to resuming traffic, a rainstorm flooded the area and water was standing on the test surface; however, below surface samples showed no significant water penetration in the traffic lane. After 30 coverages, the surface was leveled and the limestone that had been pushed out of the pit was used to make a ramp at each end of the traffic lane. Repair became necessary after 60 coverages (Figure 25).

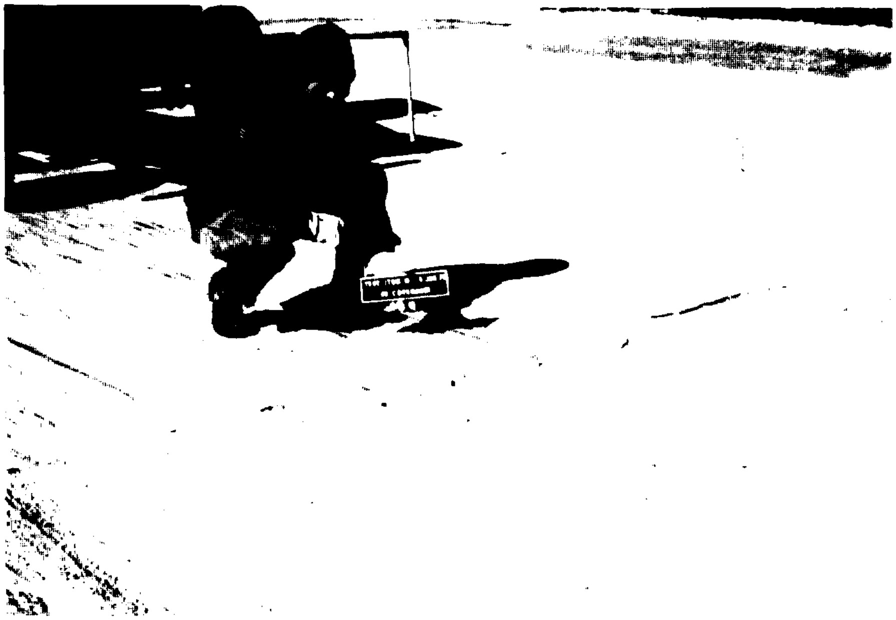


Figure 25. Surface Condition After 60 Coverages of the F-4 Load Cart

Profiles taken of the surface before repair are shown in Figure 26. Additional limestone was added to the test pit and compacted with two coverages of the RayGo 510A. The base course appeared worn and in need of repair after the completion of the 150 coverages. Profiles of the test surface after 150 coverages are shown in Figure 27. Density measurements obtained during load cart trafficking are recorded in Table 6.

TABLE 6. MEASUREMENTS DURING TRAFFICKING

F-4 COVERAGES	DEPTH (In.)	WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)
0	4	151.7	145.2	4.5
	8	152.3	145.9	4.4
	12	152.7	145.9	4.7
80	4	156.0	147.2	6.0
	8	157.5	149.0	5.7
	12	157.7	148.9	5.9
100	4	153.6	145.2	5.8
	8	157.8	149.8	5.4
	12	159.5	151.3	5.4
150	4	156.9	149.1	5.2
	8	159.1	151.9	4.7
	12	161.3	153.6	5.0

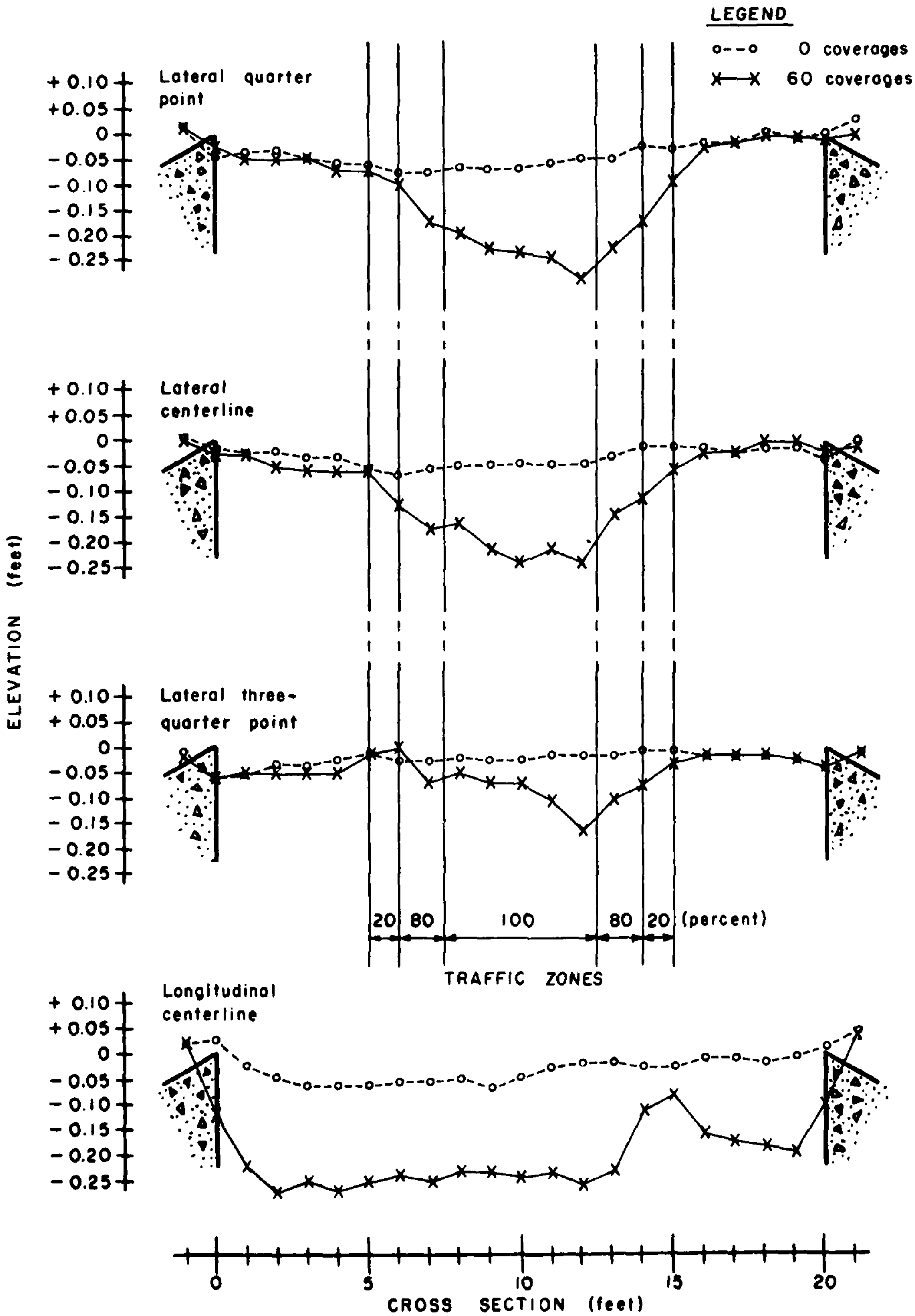


Figure 26. Surface Profiles Before Repair, Item 19

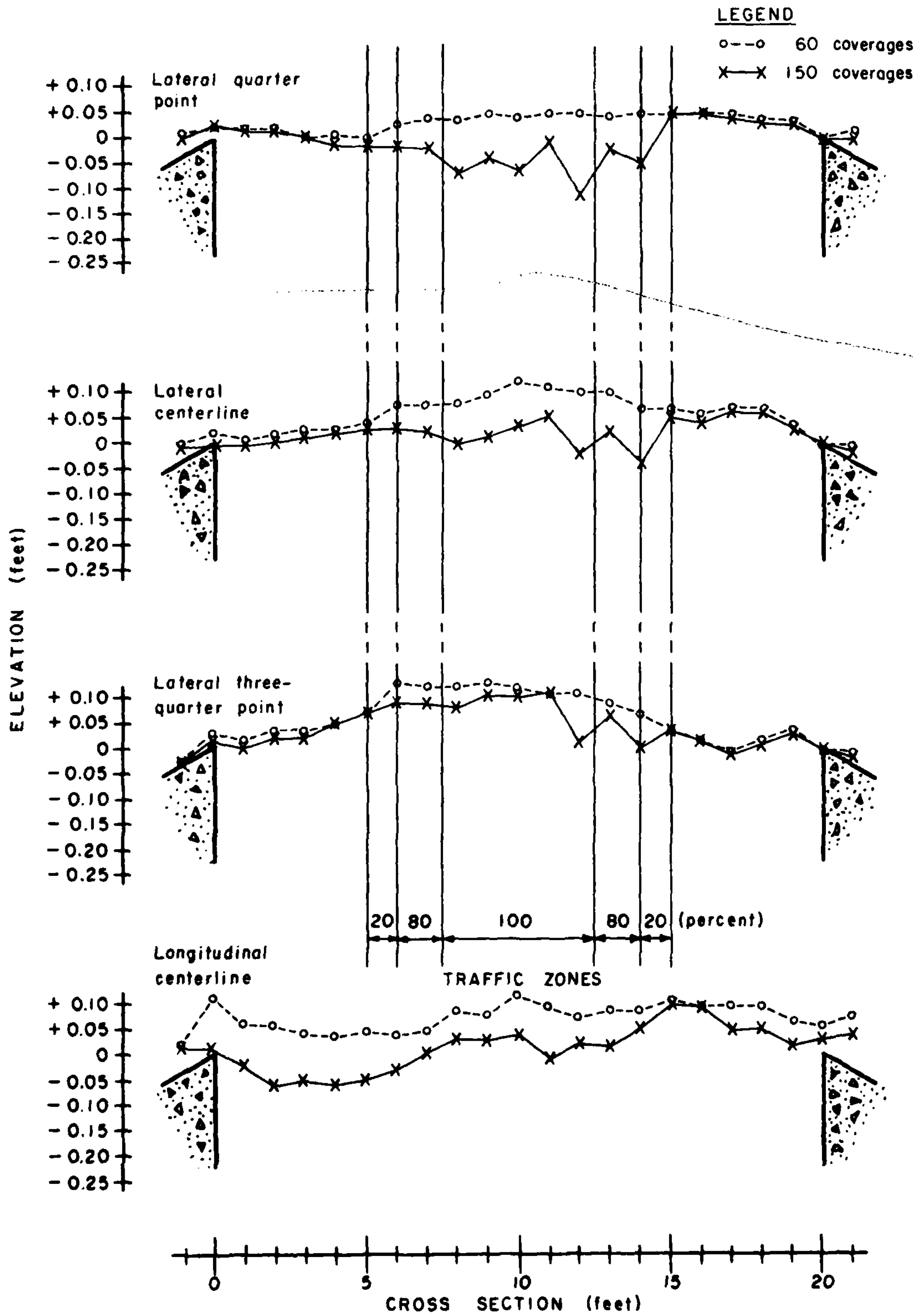


Figure 27. Surface Profiles After Repair, Item 19

CBR measurements of the surface showed a CBR of 56 in the traffic lane, a CBR of 47 out of the traffic lane, and a CBR of 7 on a spongy area in the traffic lane.

The crushed limestone contained too much moisture to support aircraft traffic. The base course became unsuitable for aircraft traffic due to flexing of the spongy surface and the excessive repairs required.

d. Item 21 - 24 Inches of Crushed Limestone, RayGo 400A, 5.5-Percent Moisture

(1) Objective. This test sought to determine the RayGo 400A's ability to achieve compaction on the same moisture content limestone as item 19 to withstand 150 coverages of the F-4 load cart. Repairs between trafficking were deemed acceptable.

(2) Procedure. Crushed limestone with a moisture content of 5.5 percent (slightly higher than item 19) was placed in the pit to a height of 29 inches above the clay subgrade and compacted level with the surrounding concrete which was 24 inches above the clay subgrade. After only 20 coverages with the compactor, the decision was made to commence F-4 load cart trafficking. The decision was based not only on the excellent appearance of the surface after the 20 coverages, but also on data derived from the compaction study (Reference 25) which showed that little increase in compaction occurred between 20 and 32 coverages. When trafficking commenced, the base course showed a dry density of 145.7 pcf. All visual and density indications suggested that the item would perform well.

(3) Results. After only six coverages, the F-4 load cart severely rutted the surface and caused a shear failure (Figure 28).

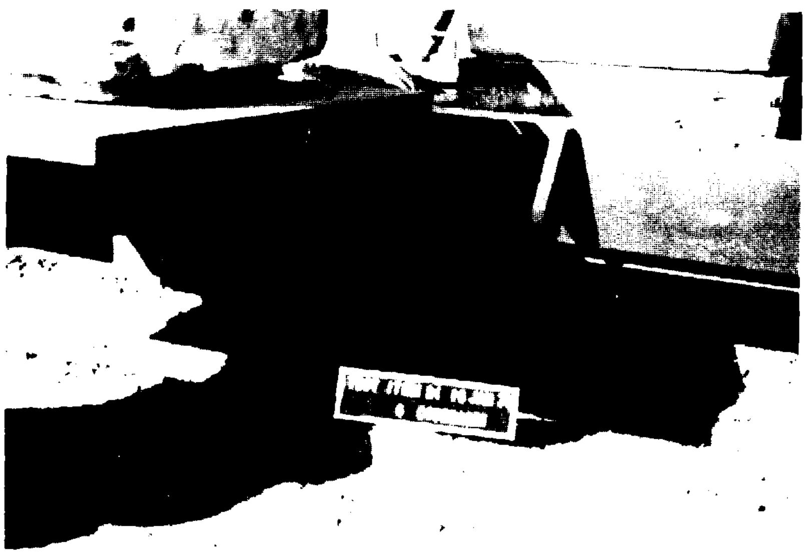


Figure 28. Shear Failure After Six Coverages of the F-4 Load Cart, Test Item 21

Though considered a failure according to Corps of Engineers criteria, the test was continued by adding more crushed stone and compacting with 12 additional coverages. Six coverages of the F-4 load cart resulted in a second failure of the test item (Figure 29).

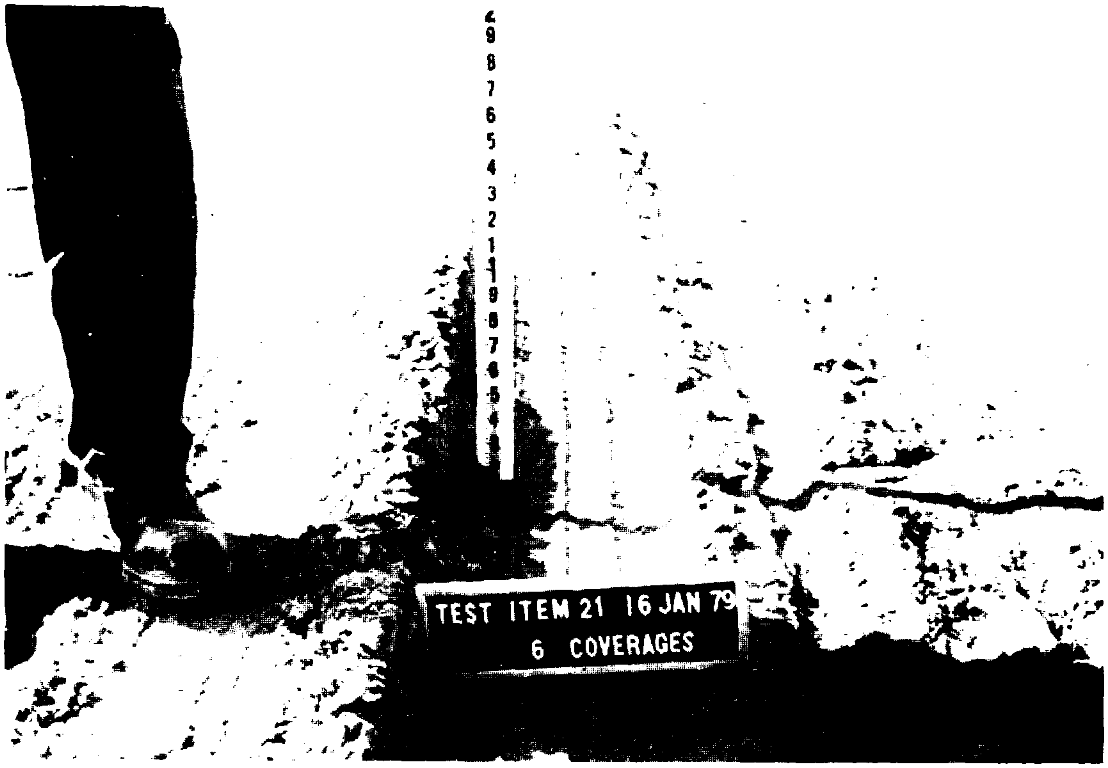


Figure 29. Second Failure After Repairing Test Item 21

Surface profiles relating to this test are given in Figure 30. Density and moisture content data obtained after the completion of six coverages of the load cart are given in Table 7.

e. Item 22 - 24 Inches of Crushed Limestone, RayGo 400A, 4.6-Percent Moisture

(1) Objective. After the failure of item 22 it was decided to experiment again with a reduced moisture content. This test evaluated crushed limestone with a reduced moisture content and, concurrently, examined the compaction rate of the RayGo 400A vibratory compactor.

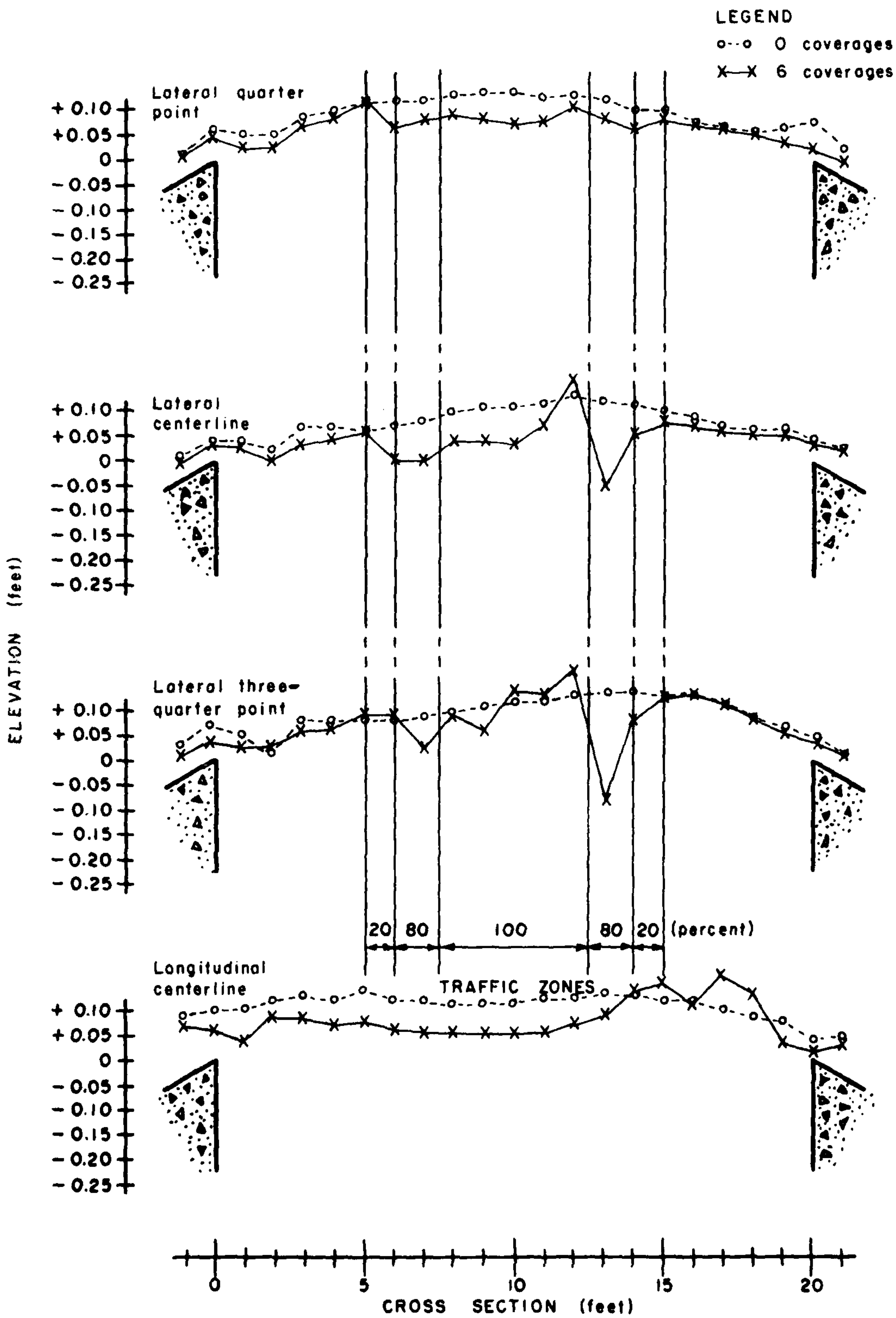


Figure 30. Surface Profiles, Item 21

TABLE 7. MEASUREMENTS, TEST ITEM 21, 24 INCHES CRUSHED LIMESTONE BASE COURSE, UNSURFACED

F-4 COVERAGES	DEPTH (In.)	IN TRAFFIC LANE			OUT OF TRAFFIC LANE		
		WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)	WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)
6	4	150.2	145.1	3.5	151.2	146.5	3.2
	8	151.3	146.3	3.4	151.1	146.7	3.0
	12	153.6	148.8	3.2	151.2	146.5	3.2
6	16	140.2	131.3	6.8	138.0	130.6	5.7
	18	144.3	135.6	6.4	140.8	133.3	5.6
	20	ND	ND	ND	143.1	135.9	5.3
6	28	122.4	95.5	28.2	121.7	93.0	30.9
	32	123.0	96.2	27.9	123.1	94.3	30.5
	36	124.6	97.7	27.5	123.0	94.3	30.5

ND No Data

(2) Procedure. The test pit was prepared in a manner identical to test item 20; the pit was overfilled to a height of 6 inches and compacted with 32 coverages of the RayGo 400A.

(3) Results. After 40 coverages with the F-4 load cart, repairs became necessary when the load cart encountered difficulty entering and exiting the pit due to consolidation of 2.25 inches in the traffic lane (Figure 31).

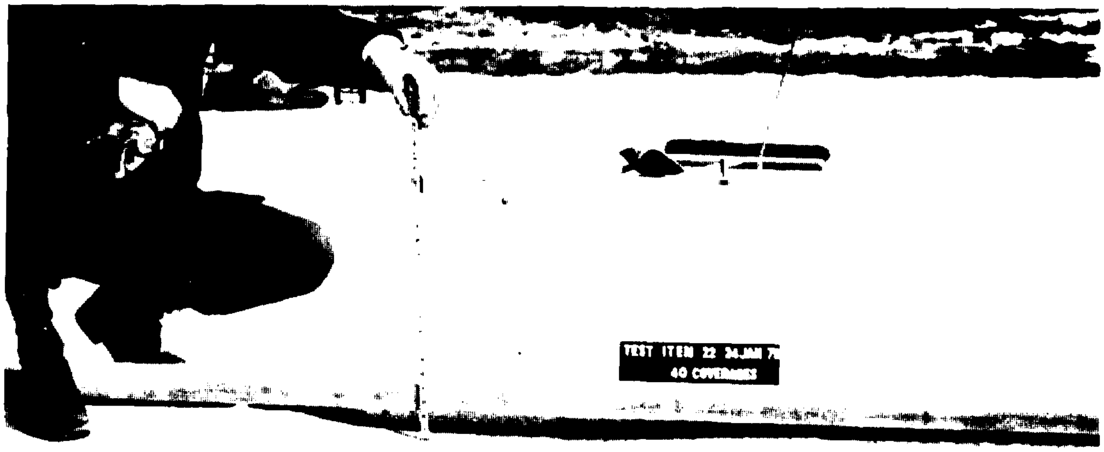


Figure 31. Consolidation of Surface After 40 Coverages, Test Item 22

Profiles obtained before repairs were made are shown in Figure 32. Crushed limestone was then added to the test pit and compacted with the RayGo 400A. One hundred fifty coverages were completed without further repair (Figure 33). Profiles taken at this point indicated maximum ruts of 2.25 inches and consolidation of 1 inch (Figure 34). After the initial 40 coverages, the rate of consolidation decreased as coverages increased. Moisture and density readings taken throughout trafficking are given in Table 8.

f. Item 24 - 24 Inches of Crushed Limestone Subjected to C-141 Load Cart Traffic

(1) Objective. After the success of item 22, this test was designed to determine the effect of C-141 load cart trafficking over a base course of 24 inches of crushed limestone previously trafficked by 150 coverages of the F-4 load cart.

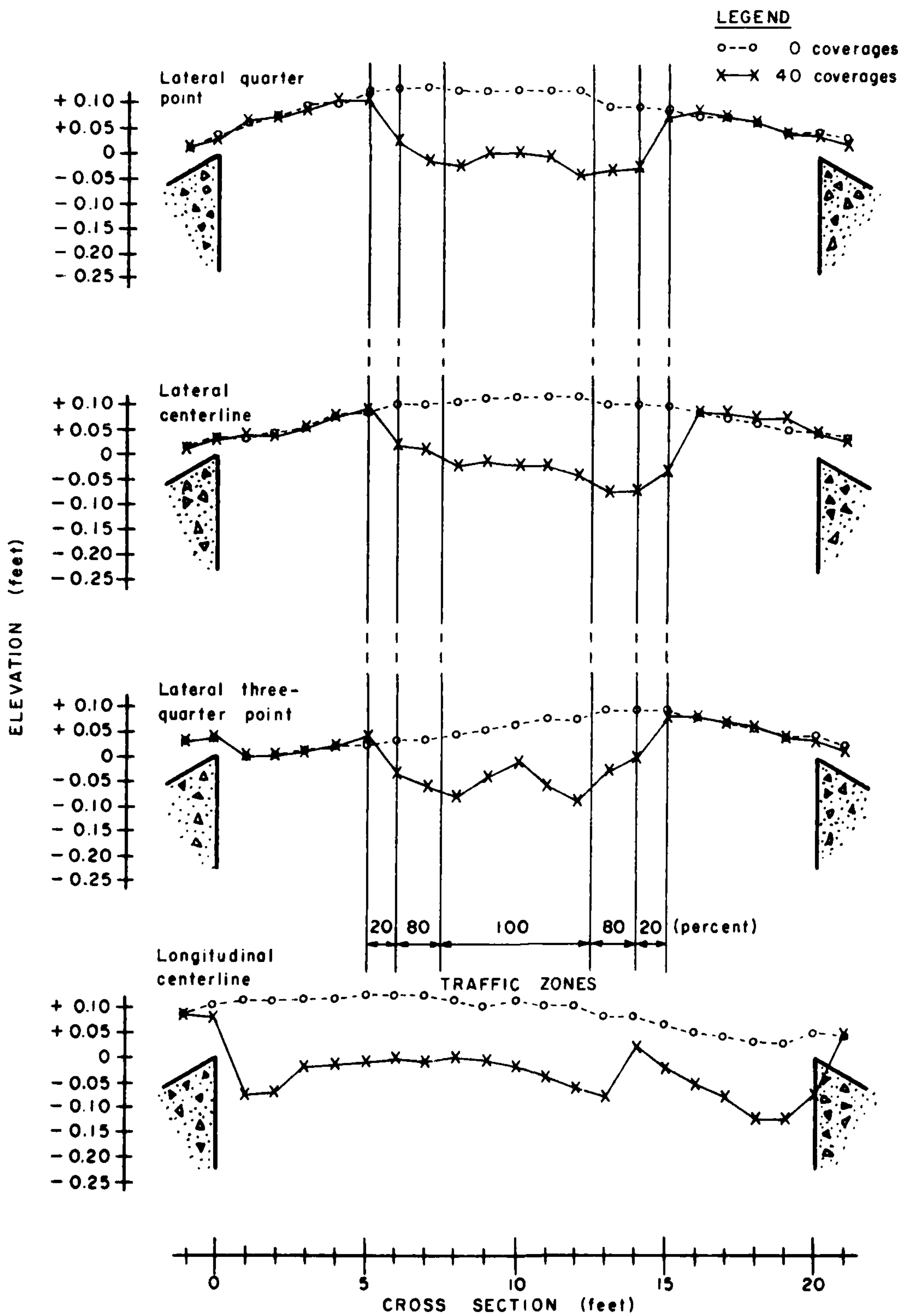


Figure 32. Surface Profiles Before Repairs, Item 22

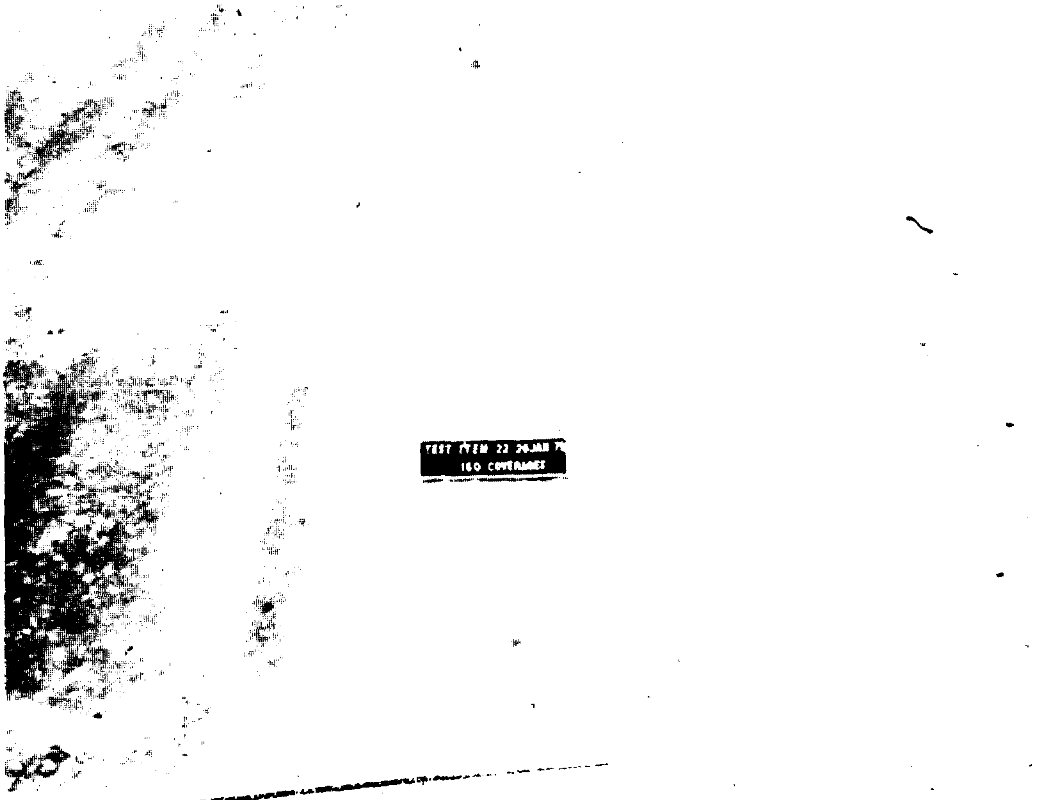


Figure 33. Surface of Test Item 22 After 150 Coverages

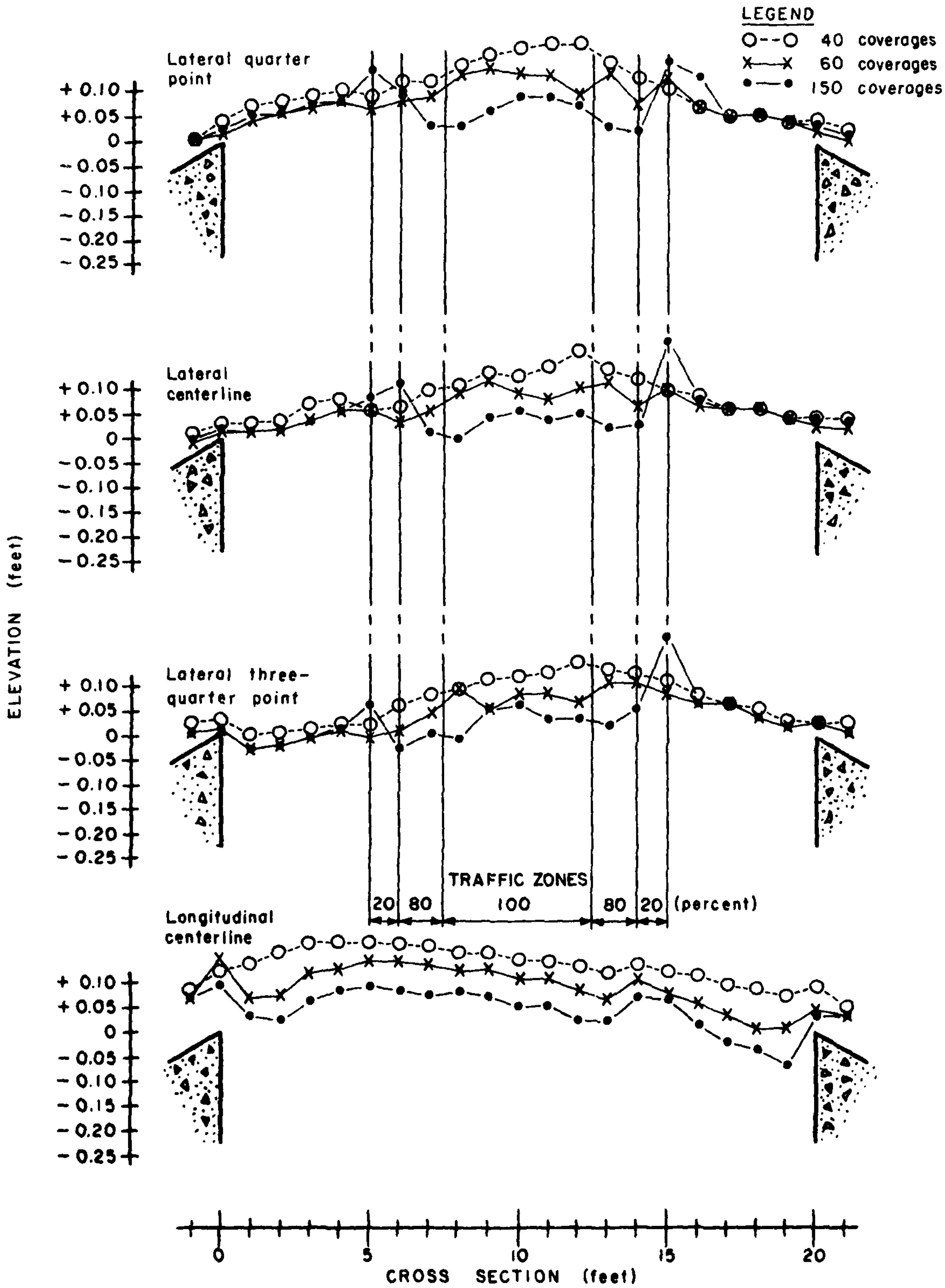


Figure 34. Surface Profiles After Repairs, Item 22

TABLE 8. MEASUREMENTS, TEST ITEM 22, 24 INCHES OF CRUSHED LIMESTONE BASE COURSE, UNSURFACED

IN TRAFFIC LANE				
F-4 COVERAGES	DEPTH (In.)	WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)
40[a]	4	145.5	140.0	3.9
	8	151.9	146.5	3.7
	12	153.1	147.8	3.6
60	4	149.6	142.7	4.8
	8	154.2	147.6	4.5
	12	155.8	148.9	4.6
80	4	151.1	145.4	3.9
	8	153.9	148.0	4.0
	12	157.2	151.3	3.9
100	4	152.8	147.1	3.9
	8	155.7	150.3	3.6
	12	158.1	152.6	3.6
150	4	156.0	150.1	3.9
	8	152.1	146.4	3.9
	12	160.4	154.4	3.9

[a] After repairs were made to the test item

(2) Procedure. This test used the repair surface constructed for test item 22. The surface was regraded before traffic was applied.

(3) Results. After 20 coverages, the surface showed rutting and deformation of approximately 0.75 inch. Completion of trafficking produced very little change of the surface; maximum deformation of 1.2 inches was recorded after 150 coverages (Figure 35).

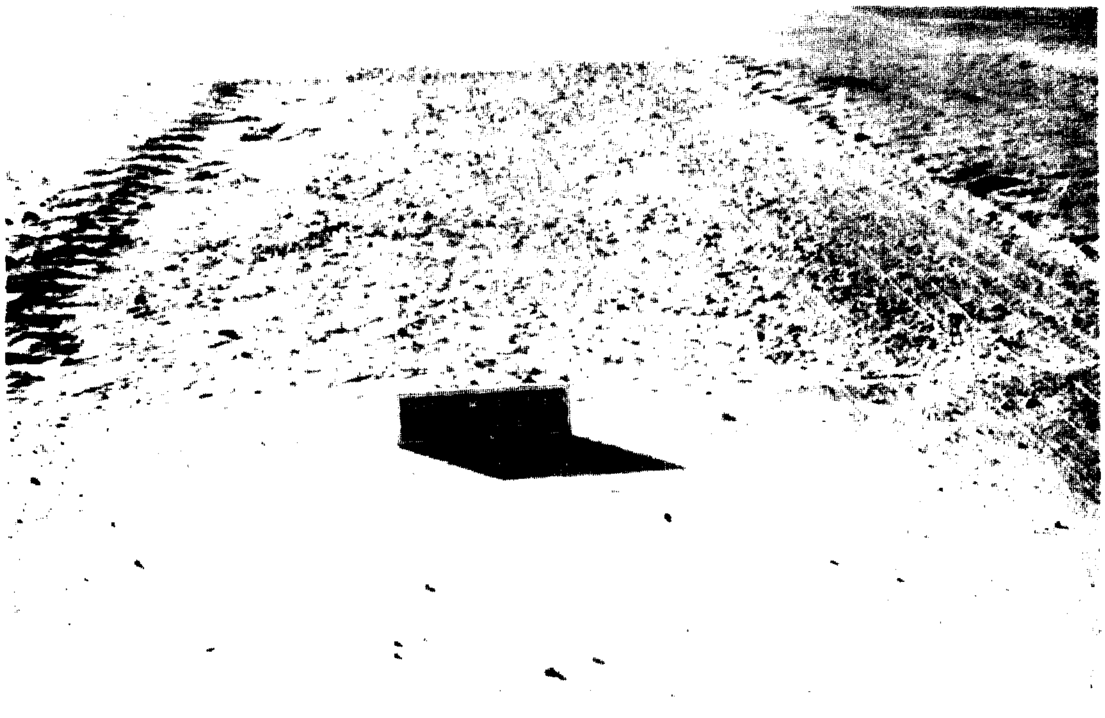


Figure 35. Results of 150 Coverages of C-141 Load Cart on Test Item 24

Profiles of the test surface are shown in Figure 36. Density readings taken are recorded in Table 9. A k value of 420 pounds per cubic inch (pci) was calculated on the surface of the base course, and a k value of 115 pci was obtained at a depth of 27 inches.

The 24-inch crushed limestone base course compacted with the RayGo 400A compactor was capable of supporting F-4 and C-141 load cart traffic within the criteria set forth by the Corps of Engineers. It appears that some drying of the base course had occurred after completion of test item 22, reducing the moisture content from 3.9 percent to an average of 3.2 percent.

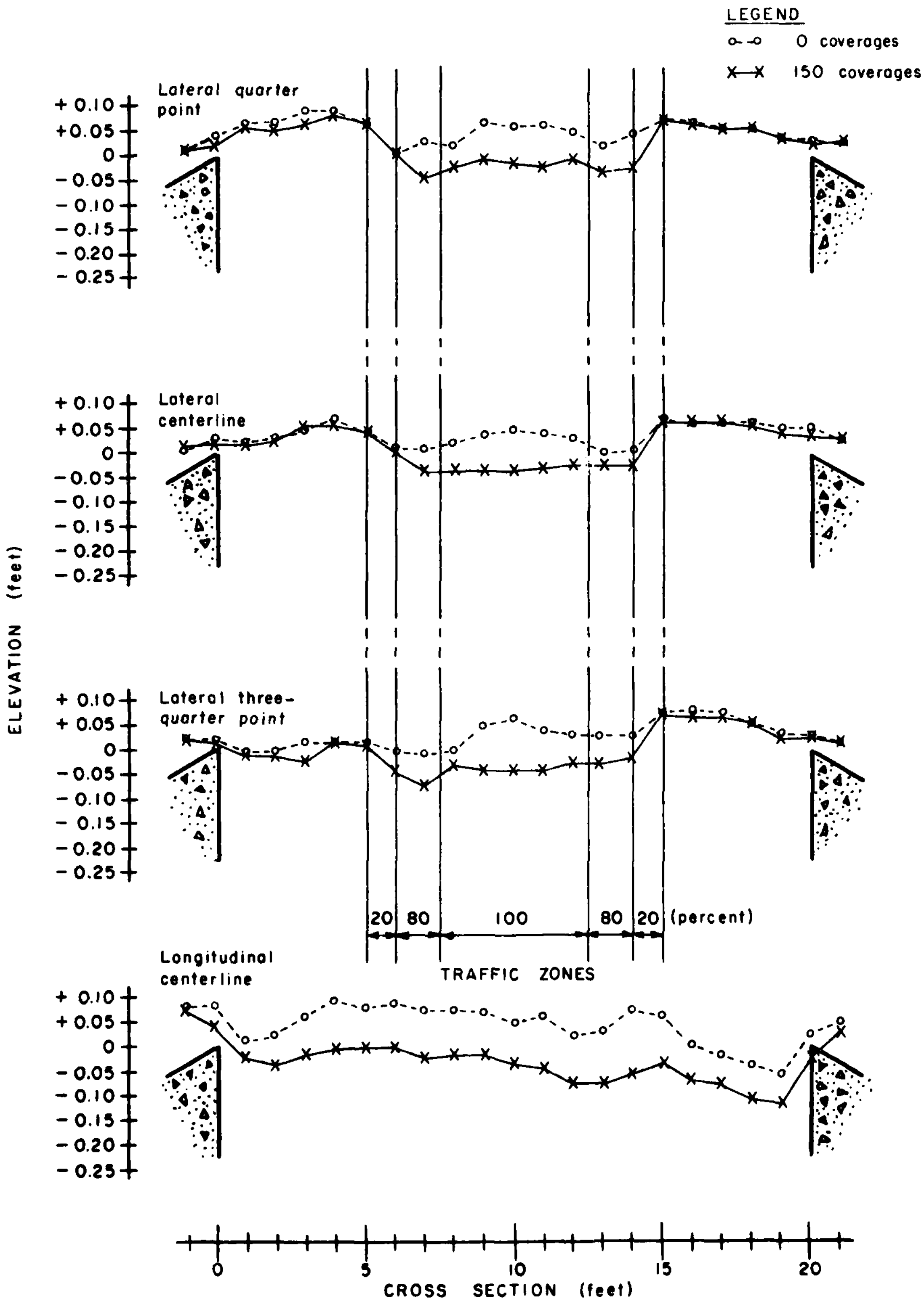


Figure 36. Surface Profiles, Item 24

TABLE 9. MEASUREMENTS, TEST ITEM 24, 24 INCHES CRUSHED LIMESTONE BASE COURSE, UNSURFACED

C-141 COVERAGES	DEPTH (In.)	IN TRAFFIC LANE			OUT OF TRAFFIC LANE		
		WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)	WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)
0 [a]	4	156.0	150.1	3.9	ND	ND	ND
	8	152.1	146.4	3.9			
	12	160.4	154.4	3.9			
150	4	154.6	150.8	2.5	151.1	146.8	2.9
	8	157.6	153.4	2.4	152.6	149.5	2.1
	12	158.6	154.9	2.4	153.0	149.7	2.2
	16	149.4	150.0	2.9	143.0	137.6	3.9
	20	151.5	146.9	3.1	144.9	139.5	3.9
	24	152.7	148.4	2.9	148.3	143.1	3.6
	28	121.1	92.8	30.5	121.1	93.9	29.0
	32	123.2	95.1	29.6	122.8	95.9	28.1
	36	125.1	97.9	27.2	123.1	95.9	28.3

[a] Readings taken at completion of Test Item 22.

ND No Data

g. Item 25 - RayGo 510A, 5.6-Percent Moisture

(1) Objective. As the fifth item in the series of tests involving crushed limestone, this test was designed to determine the effect of high moisture content on compaction and ability of the unsurfaced base course to meet trafficability requirements. Evaluation of the RayGo 510A was included in this item's objective.

(2) Procedure. Soil preparation, placement, and compaction was identical to preceding test items; graded crushed limestone was spread out on a mixing pad, water added to obtain the desired moisture content, thoroughly mixed and then placed in the test pit. Thirty-two coverages of the RayGo 510A were applied to the base course. Measurements taken during compaction are presented in Table 10.

(3) Results. After compaction, prior to initiation of F-4 load cart traffic, water was seen standing in the low spots of the base course. After two F-4 load cart coverages, rutting started and a soft spot was detected near the center of the test pit (Figure 37).

Figure 37. Rutting of Base Course After Two Coverages, Test Item 25

Rutting and deformation grew progressively worse until a shear deformation failure occurred after the 26th coverage when the load cart had severely rutted the limestone base course (Figure 38).

TABLE 10. MEASUREMENTS, TEST ITEM 25, 24 INCHES OF 1.5-INCH SIZED CRUSHED LIMESTONE BASE COURSE, UNSURFACED

RAYGO 510A COVERAGES	DEPTH (In.)	WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)
8	4	150.1	142.1	5.6
	8	150.2	142.2	5.6
	12	150.0	141.9	5.7
16	4	149.0	141.1	5.6
	8	149.6	141.5	5.7
	12	149.1	140.7	5.9
20	4	156.6	144.7	8.2
	8	156.7	145.4	7.8
	12	156.1	145.9	7.0
24	4	152.2	143.3	6.2
	8	151.8	142.8	6.3
	12	153.0	144.3	6.0
32	4	153.4	142.6	7.6
	8	152.1	140.8	8.0
	12	ND	ND	ND

ND No Data

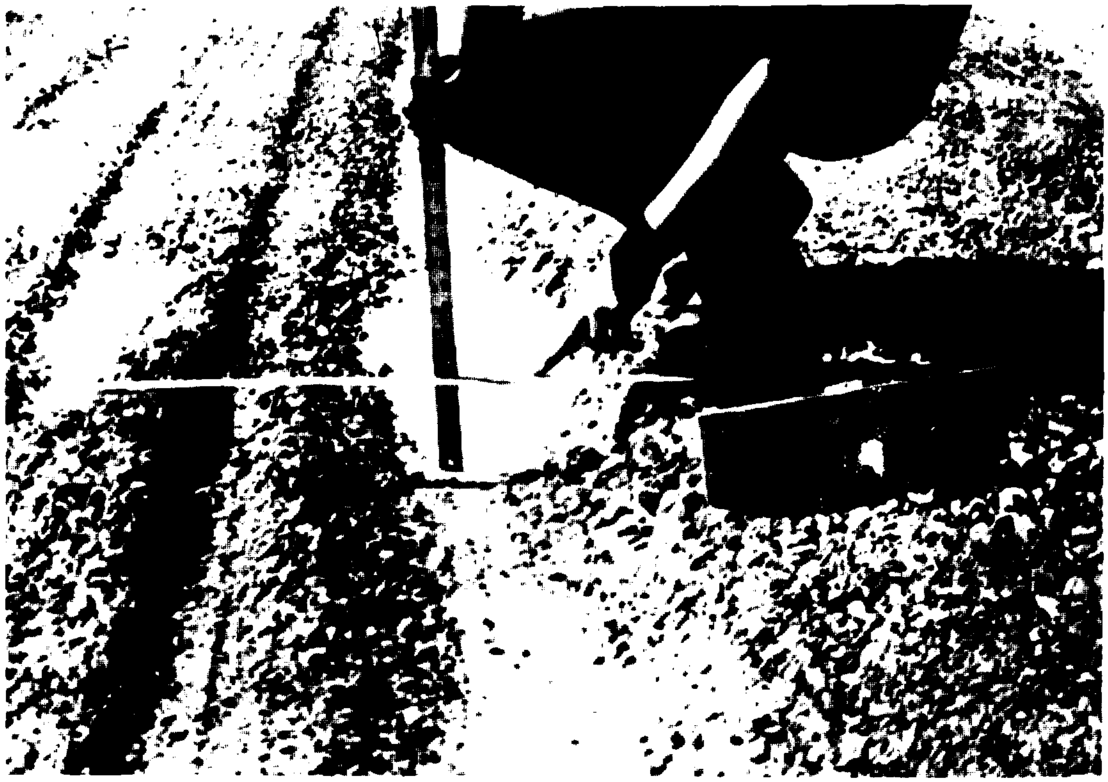


Figure 38. Failure of Test Item 25 Due to Shear Deformation

Readings obtained at the point of failure indicated 7.7-percent moisture and a dry density of 145.1 pcf. After repairs were made, four more coverages were achieved before the surface again became unsuitable for further trafficking. Surface profiles taken at the start of trafficking, and after 20 and 26 coverages, are shown in Figure 39. A plate survey of the subgrade indicated a consolidation of 0.02 foot.

Comparison of item 25 results with data derived from item 21, both designed with a high moisture content, and both termed failures, led to the conclusion that moisture content had an effect on the ability of the crushed limestone to support aircraft trafficking. However, test item 25, compacted with the heavier RayGo 510A, sustained the greater number of load cart coverages before failure.

h. Item 26 - RayGo 400A, 3.0-Percent Moisture

(1) Objective. After review of preliminary findings derived from preceding tests with high moisture stone, it was decided to continue the experiment using crushed limestone with a moisture content of 3.0 percent, the prevailing stockpile moisture. Compaction with the RayGo 400A was to provide additional data for the continuing evaluation of the two vibratory rollers.

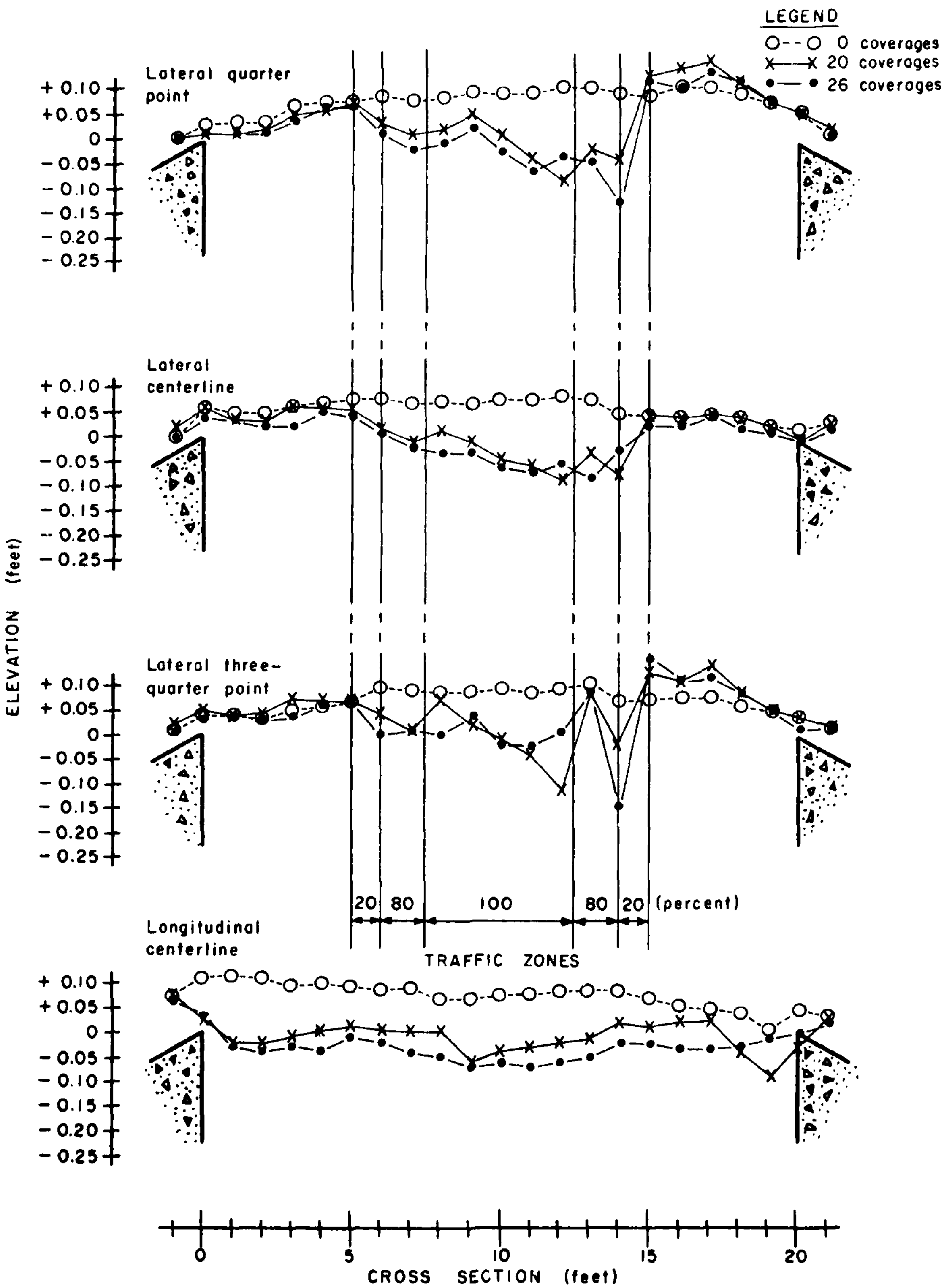


Figure 39. Surface Profiles, Item 25

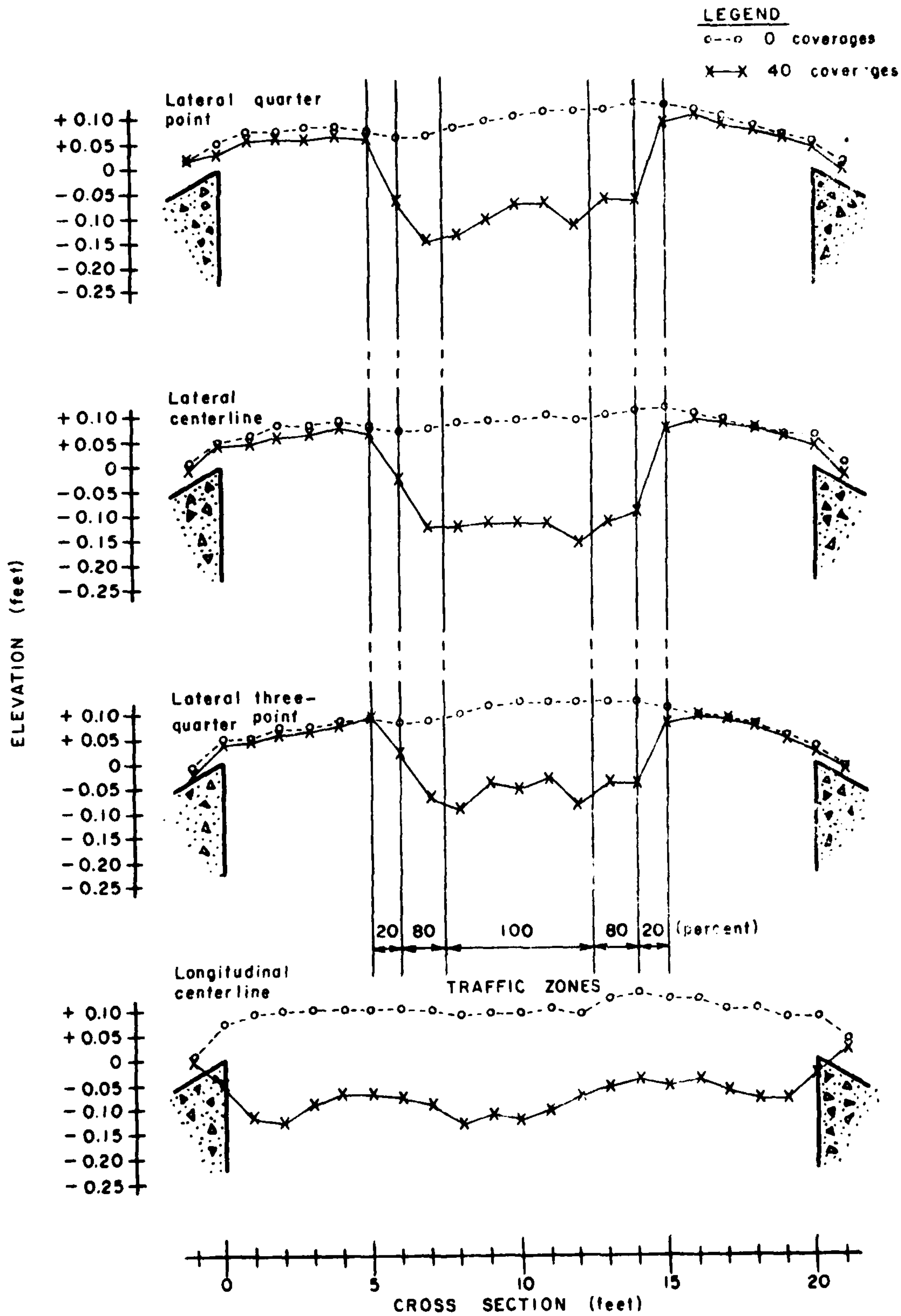


Figure 40. Surface Profiles Before Repairs, Item 26

(2) Results. After compaction, the limestone showed a moisture content of 2.8 percent and a dry density of 141.7 pcf. Twenty coverages of the F-4 load cart produced deformations of approximately 2 inches; deformations had increased to 3 inches after 40 coverages when it became necessary to add limestone and repair the surface. Figure 40 provides profile data prior to repairs. After 60 coverages, the surface deformation was as shown below (Figure 41).

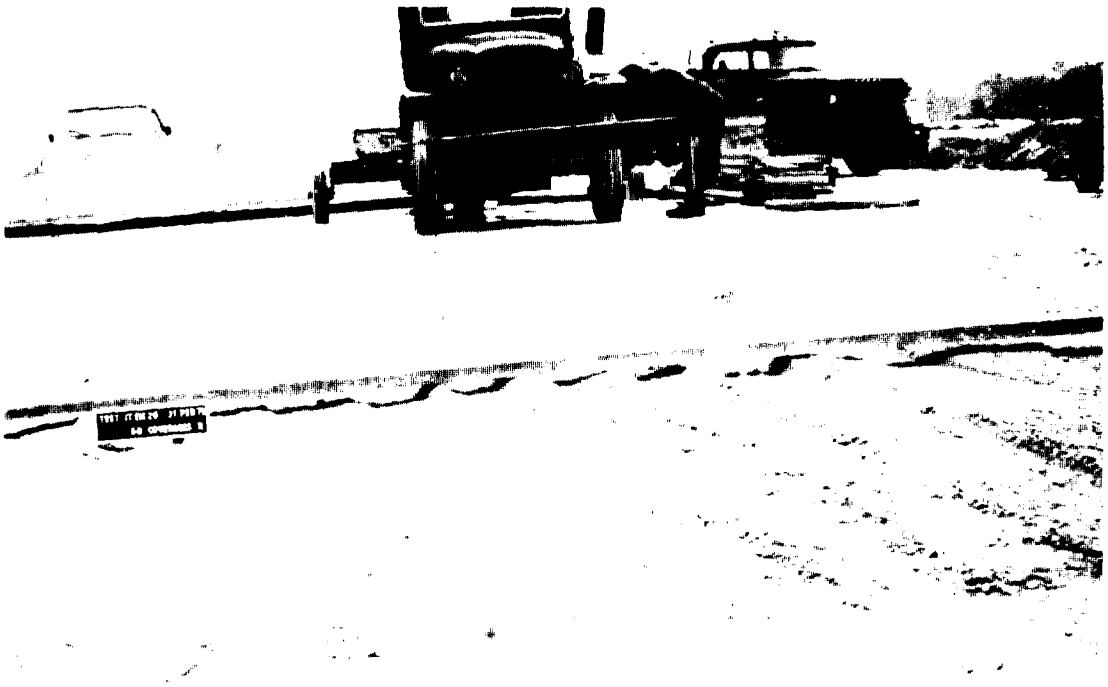


Figure 41. Surface Deformations After 60 Coverages, Test Item 26

Figure 42 shows profiles at 60 and 150 coverages when trafficking was completed without further repairs. Consolidation in the traffic lane measured 1 inch with 3-inch ridges between ruts. The clay subgrade in the traffic lane had consolidated 0.1 inch. The crushed limestone base course with a moisture content of 2.2 percent after 150 F-4 load cart coverages was termed successful. The lesser moisture content was seen as a positive factor in stabilizing the repair.

i. Item 27 - RayGo 510A and Item 28 - RayGo 400A, 5.5-Percent Moisture

(1) Objective. These tests were conducted simultaneously to evaluate the performance of the smaller and larger vibratory roller under duplicate conditions. Resulting data was to provide a basis for the procurement decision and subsequent in-house use of the candidate roller.

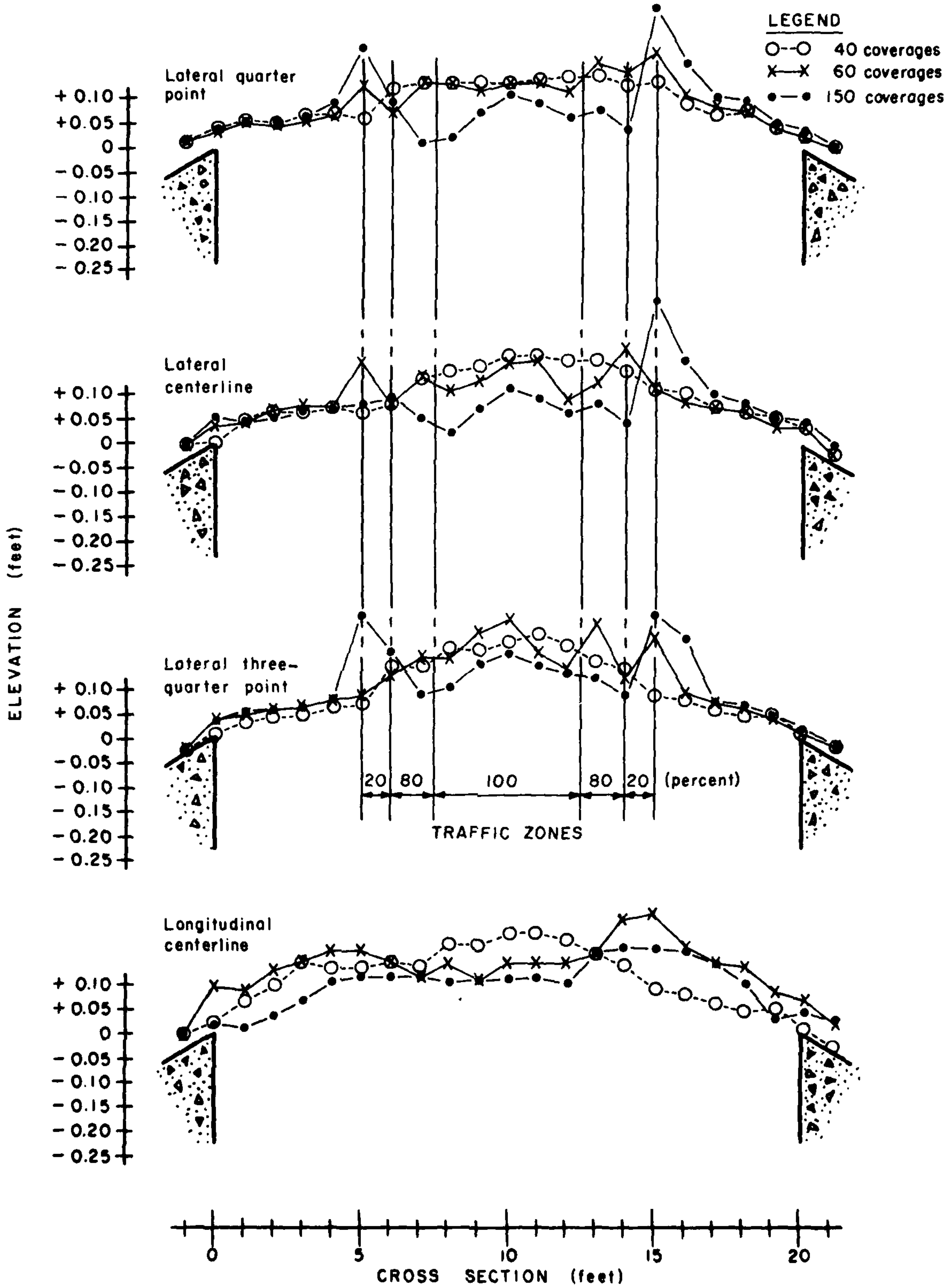


Figure 42. Surface Profiles After Repairs, Item 26

(2) Procedure. Water was added to a quantity of crushed limestone sufficient for two test pits. After mixing, successive bucket-loads of stone were equally distributed between the two pits in an effort to minimize any variance in the moisture content.

(3) Compaction. The RayGo 510A compacted test item 27 and the RayGo 400A compacted item 28. After four coverages by the vibratory rollers, the RayGo 510A had compacted the base course to a level 1.0 inch below the surrounding concrete, while the RayGo 400A had compacted test item 28 by 0.5 inch. After limestone had been added to each pit, grading and compacting were continued. After 16 coverages, both test items showed signs of elasticity where water had been drawn to the surfaces. After 32 coverages, water still remained on the surface, with test item 28 (RayGo 400A) showing a larger accumulation. Moisture and density readings taken at successive stages of compaction are shown in Table 11. A graphic comparison of compaction results is portrayed in Figure 43.

TABLE 11. MEASUREMENTS DURING COMPACTION, ITEMS 27 AND 28

		RayGo 510A			RayGo 400A		
		Test Item 27			Test Item 28		
Coverages	Depth (in)	Wet Density (pcf)	Dry Density (pcf)	Moisture Content (%)	Wet Density (pcf)	Dry Density (pcf)	Moisture Content (%)
	4	141.3	134.2	5.3	142.8	135.2	5.6
4	8	141.6	134.6	5.2	143.0	135.8	5.3
	12	141.9	134.6	5.4	142.8	135.5	5.4
	4	143.5	136.8	4.9	146.0	138.7	5.3
8	8	145.1	138.3	4.9	146.3	139.1	5.2
	12	145.3	138.5	4.9	146.7	139.3	5.3
	4	146.7	139.8	4.9	147.4	140.0	5.3
12	8	147.8	140.8	5.0	147.4	140.1	5.2
	12	148.3	141.1	5.1	146.7	139.6	5.1
	4	148.0	141.1	4.9	146.0	138.7	5.3
16	8	148.4	141.1	5.2	148.2	140.9	5.2
	12	148.4	141.5	4.9	148.0	141.0	5.0
	4	149.6	142.1	5.3	148.7	140.1	5.5
24	8	149.3	141.5	5.5	149.4	141.5	5.6
	12	149.2	141.4	5.5	148.9	141.0	5.6
	4	150.4	142.7	5.4	148.1	139.7	6.0
32	8	149.9	142.1	5.5	149.1	140.9	5.8
	12	152.3	144.5	5.4	152.0	144.5	5.2

(4) Results. The F-4 load cart was used to traffic both test items, alternating between pits. After four coverages on each item, the load cart severely rutted the base course surface of test item 28 (compacted with the RayGo 400A) due to shear failure. Item 28 was termed a failure at this point; however, it was decided to make repairs and to

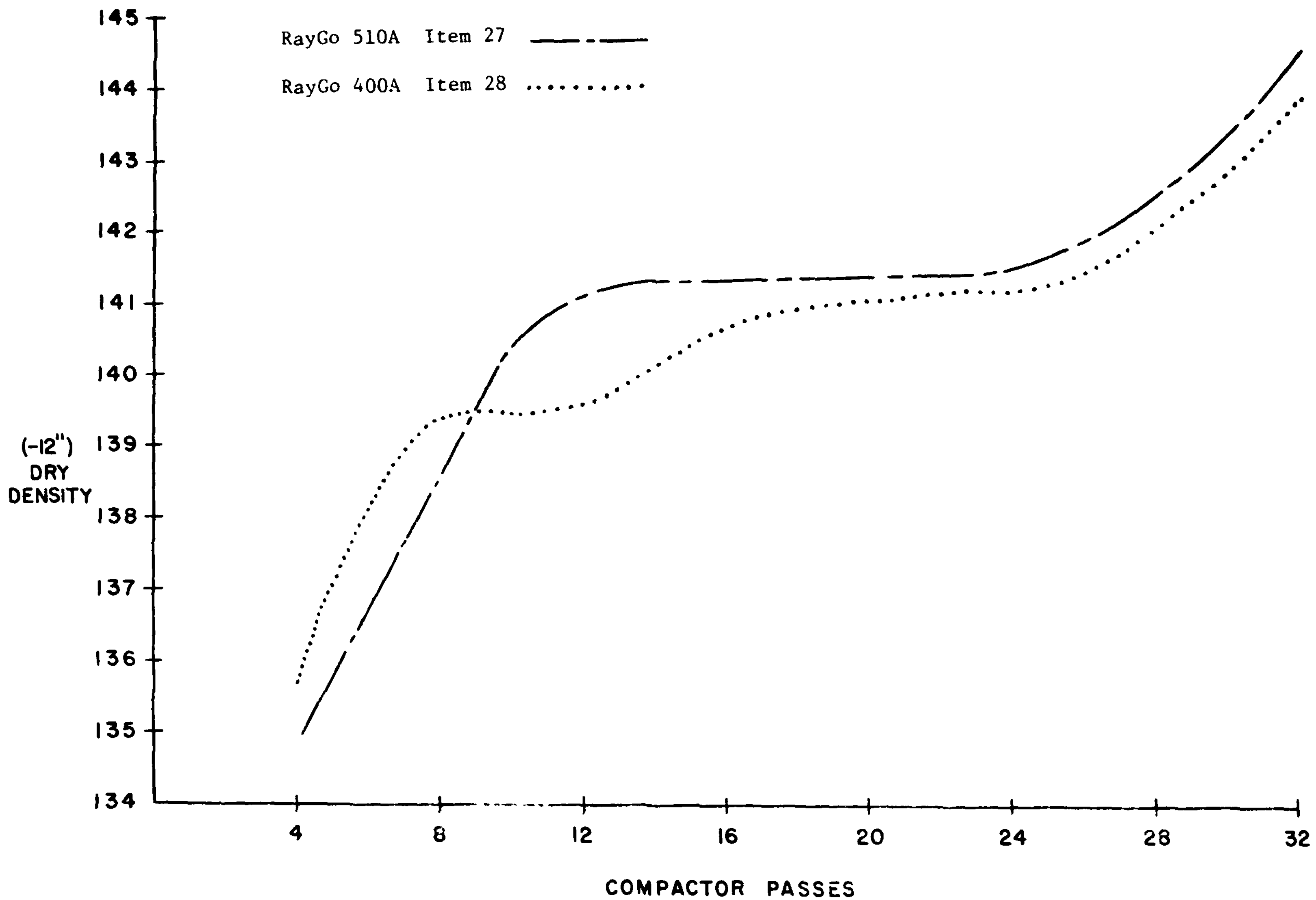


Figure 43. Compaction Results, Items 27 and 28

continue the evaluation in order to obtain additional data. Limestone was then added to item 28 and compacted with eight coverages of the RayGo 510A. Although no standing water was visible after compaction, item 28 was characterized as spongy and unstable. Two passes of the F-4 load cart confirmed the suspicion that the repaired test item possesses very little strength. Additional trafficking resulted in progressive deterioration of the surface until further testing of item 28 was abandoned after 24 coverages. After four coverages, test item 27 had encountered much less of a problem, showing deflections of less than 1 inch. Test item 27 sustained 48 coverages before a hump developed in the center of the pit, causing a near-failure. Repairs were made at this point and trafficking continued. Two more repairs were necessary before the failure criteria was exceeded during the 98th coverage (Figure 44).

Figure 44. Failure of Test Item 27 (RayGo 510A) After 98 Load Cart Coverages

Surface profiles of item 27 are shown in Figure 45.

j. Item 32 - Crushed Limestone Base Course, 2.0-Percent Moisture, C-141 Load Cart Traffic

(1) Objective. Previous tests using crushed limestone as an unsurfaced base course applied C-141 load cart traffic only after consolidation of the test item had already occurred as a result of F-4 load cart

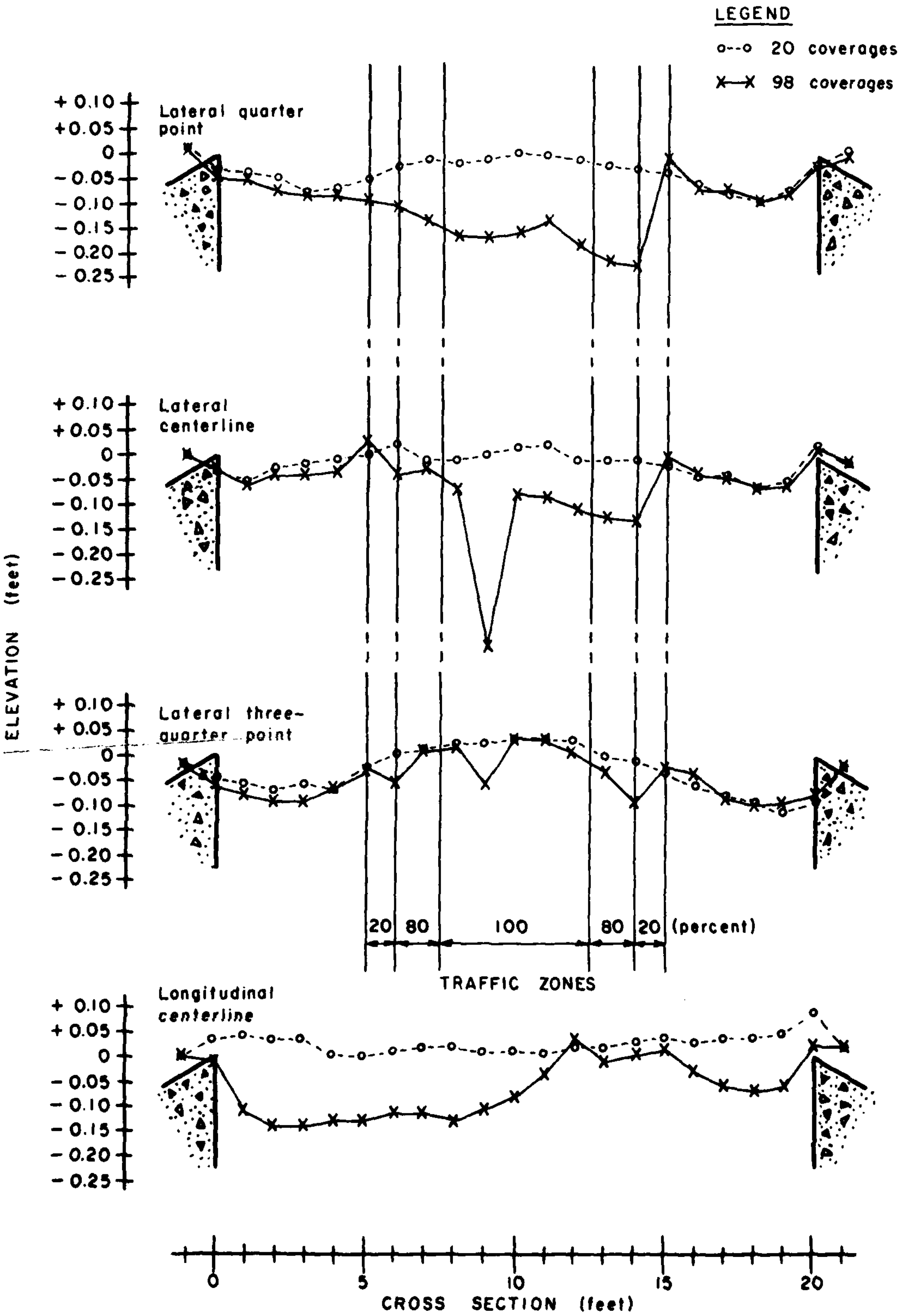


Figure 45. Surface Profiles, Item 27

traffic. This test was designed to obtain data on the effects of C-141 traffic on a crushed limestone test item with a 2.0-percent moisture content which had been compacted with a RayGo 400A vibratory roller.

(2) Procedure. The clay subgrade was profiled, and approximately 29 inches of crushed limestone were placed in the pit and compacted with 32 coverages of the RayGo 400A. A dry density of approximately 139.7 pcf and a moisture content of 1.9 percent were recorded at a depth of 4 inches in the traffic lane.

(3) Results. After 20 coverages of the load cart, a small amount of rutting and pushing of the material at each end of the traffic lane had occurred. Profiles of the test surface indicated consolidation of approximately 2.4 inches. After 40 coverages, the maximum deformation was 2.8 inches, indicating that the rate of deformation was decreasing. The drop from the concrete pad to the base course after 60 coverages made it difficult for the load cart to enter and exit the test pit, necessitating repair of the test pit. Profiles were taken of the test surface prior to repair and are shown in Figure 46. Additional limestone was placed on the traffic lane and compacted within 12 coverages of the RayGo 400A. After 70 coverages of the load cart, the added base course had become fluffy and appeared to have lost its compaction. It was shoving badly under the wheel of the load cart, and the difference between the bottom of the ruts and the top of the ridges measured approximately 3.5 to 4.5 inches. The limestone was overlapping each end of the pit about 8 inches and created a FOD problem.

The overlapped base course was placed back into the traffic lane, and the ridges leveled down after 80 coverages (Figure 47). After 120 coverages, the limestone appeared to be too dry. A hand pump was used to pump water onto half of the test surface. Trafficking resumed until 150 coverages were completed (Figure 48). The added moisture appeared to help stabilize the base course and reduced the amount of surface repairs required. Profiles (Figure 49) and density readings (Table 12) were taken for specified coverages. CBR tests were conducted, and a CBR of 80 was obtained in the in-traffic lane and a CBR of 110+ in the out-of-traffic lane. The subgrade showed a maximum consolidation of 0.24 inch along the center of the traffic lane.

Rutting and shoving were evident throughout the test. The low moisture content of the base course tended to cause the limestone to resist compaction. This was indicated by the compaction of the limestone that occurred after the water was added. The results support conclusions of an optimum moisture content of approximately 2.5 to 3.0 percent.

k. Summary of Test Results - Crushed Limestone

(1) Overall Results. Nine test designs employed limestone as an unsurfaced base course for expedient crater repair; five were termed successful, having achieved 150 coverages (1440 passes) of load cart traffic simulating F-4 or C-141 aircraft. Four test items were rated failures or marginal.

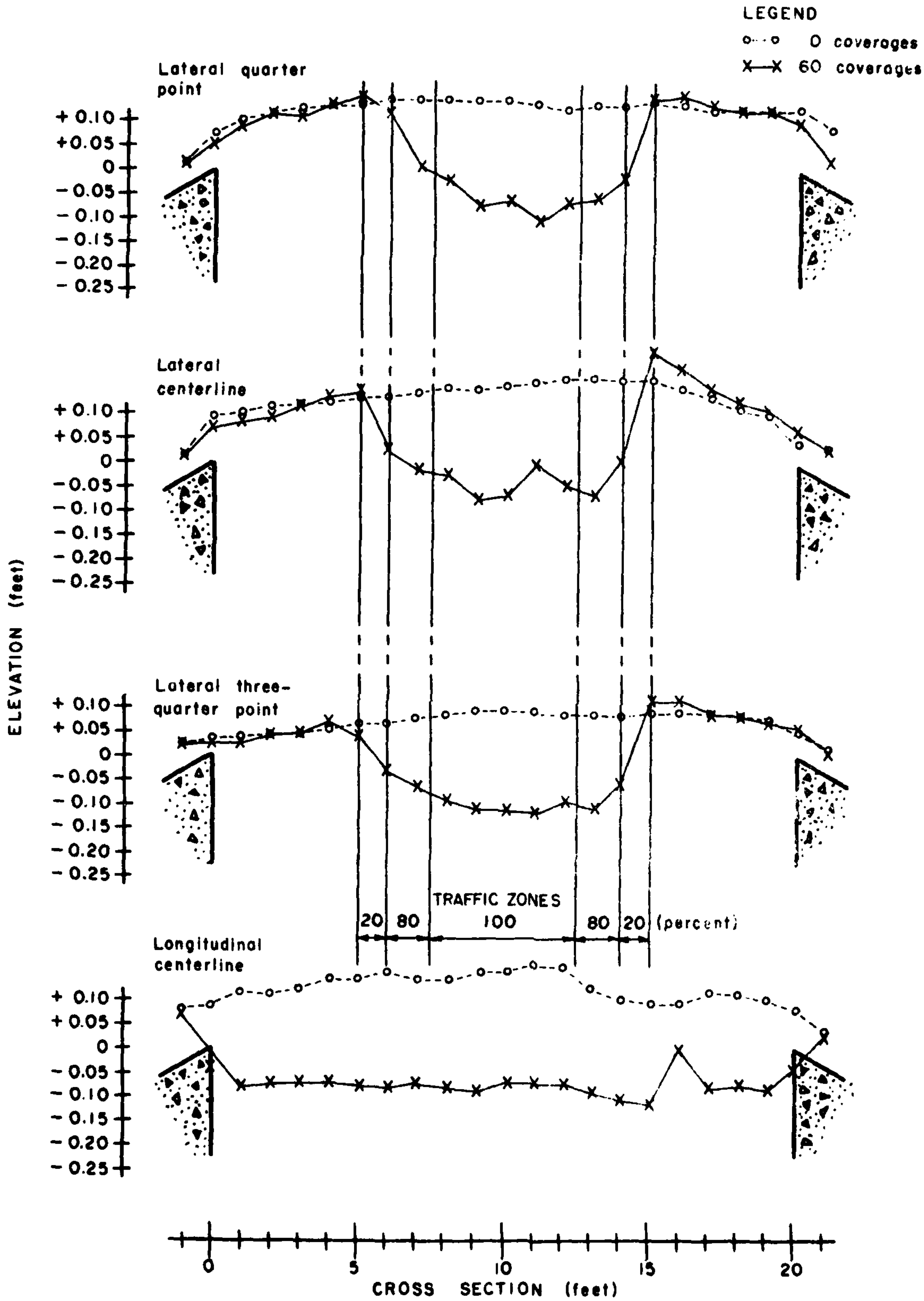


Figure 46. Surface Profiles Before Repairs, Item 32

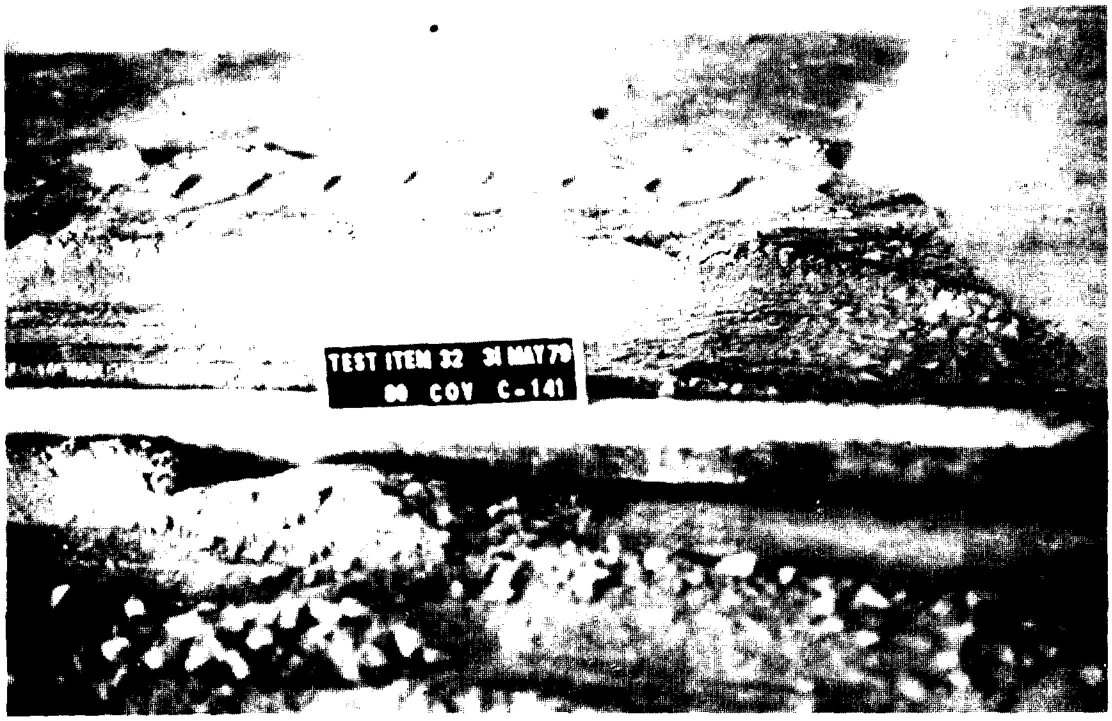


Figure 47. Rutting and Overlapping, Test Item 32

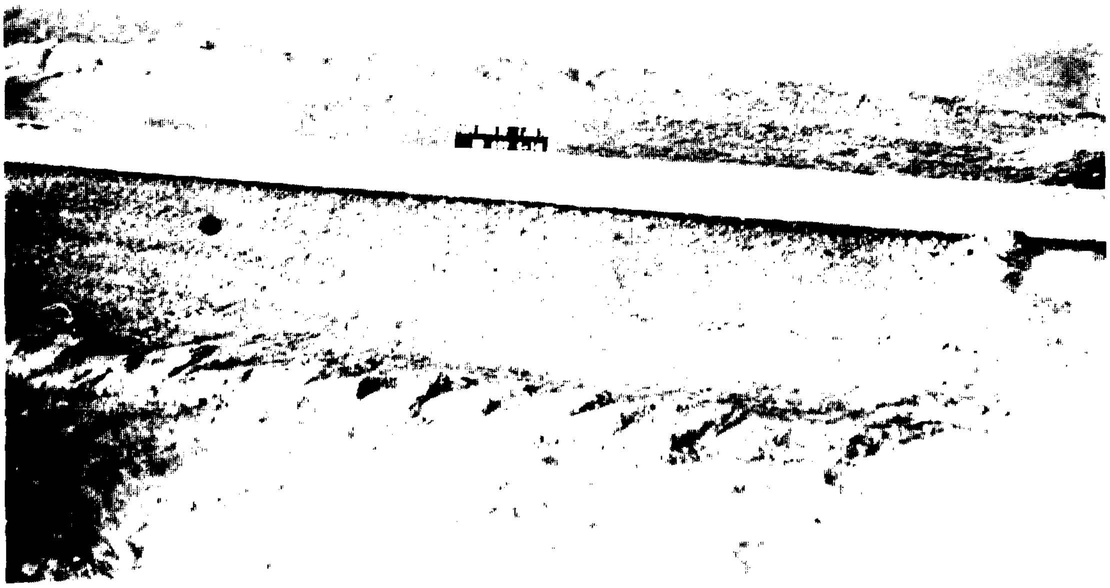


Figure 48. Consolidation of Base Course, Test Item 32

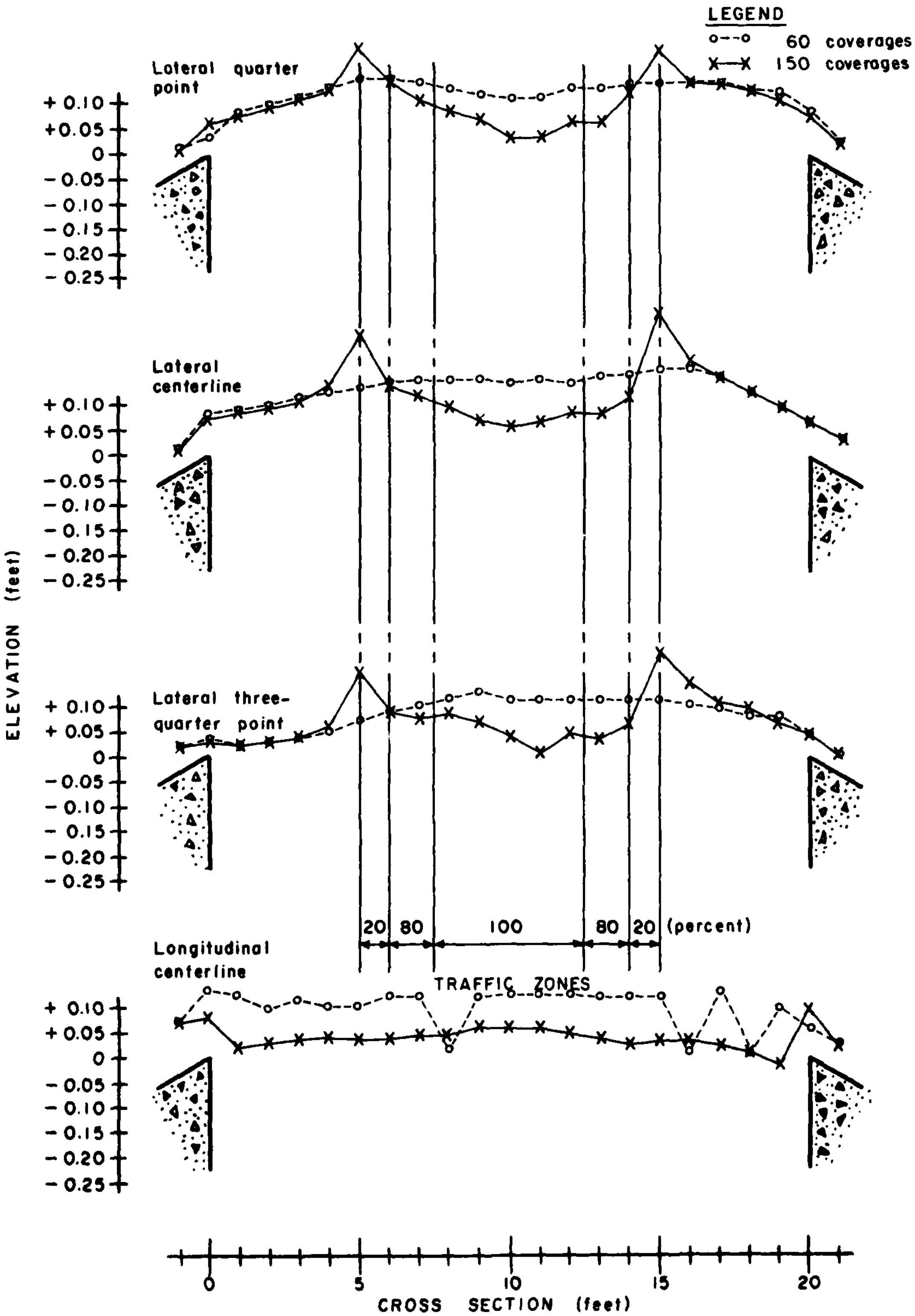


Figure 49. Surface Profiles After Repair, Item 32

TABLE 12. MEASUREMENTS, TEST ITEM 32, 24 INCHES CRUSHED LIMESTONE BASE COURSE, UNSURFACED

C-141 COVERAGES	DEPTH (In.)	IN TRAFFIC LANE			OUT OF TRAFFIC LANE		
		WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)	WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)
0	4	142.4	139.7	1.9	ND	ND	ND
	8	141.8	139.3	1.8			
	12	141.0	138.4	1.9			
150	4	149.2	146.3	2.0	144.3	142.3	1.4
	8	149.8	146.9	2.0	141.7	139.6	1.5
	12	150.6	147.6	2.0	140.0	137.9	1.5
150[a]	4	154.5	150.3	2.8	ND	ND	ND
	8	150.2	146.0	2.9			
	12	149.6	145.5	2.8			

a Water was added to this area

ND No Data

(2) RayGo Vibratory Rollers. Collection of performance data on RayGo vibratory rollers used for the compaction of the limestone constituted an ancillary objective of the series crushed limestone tests. Results of these evaluations are the subject of a separate report (Reference 25).

(3) Density After Compaction and Moisture Content. A review of the vibratory roller study and the data summarized in Table 13, shows that:

- Density achieved after compaction was not a determining factor in achieving an item's success (i.e., 150 coverages);
- High moisture content, however, seemed to constitute the common factor for test items which failed.

As shown in the data summary, items termed *failures had moisture content* in excess of 5.0 percent.

TABLE 13. DATA SUMMARY - CRUSHED LIMESTONE TEST ITEMS

Test Item	RayGo Vibratory Roller Used	Moisture Content[a] Percent	Load Cart Coverages Achieved F-4	Load Cart Coverages Achieved C-141	Coverages Before Repair	Result[b]
19	510A	5.0	150	ND	60	Success
21	400A	5.5	12	ND	6	Failure
22	400A	4.6	150	ND	40	Success
24[c]	400A	3.2	ND	150	ND	Success
25	510A	5.6	26	ND	20	Failure
26	400A	3.0	150	ND	[illegible]	Success
27	510A	5.5	98	ND	48	Marginal
28	400A	5.5	24	ND	4	Failure
32	400A	2.0	ND	150	60	Success

[a] Moisture content measured at start of test

[b] Success or failure based on completion of 150 coverages

[c] Item 24 was subjected previously to 150 coverages of F-4 load cart traffic as test item 22

ND No Data

4. FOREIGN OBJECT DAMAGE (FOD) COVERS

It has long been recognized that the most serious FOD hazard in an unsurfaced repair derives from stones and debris kicked up by aircraft

tires. The following test items examined the T-17 membrane, Amalgapave® (a patented patching material), polymer concrete, and a FRP membrane as candidate materials or systems to resolve the FOD problem.

a. Item 20 - One Inch Amalgapave® over Crushed Limestone

(1) Objective. This test was conducted to examine the feasibility of using 1 inch of Amalgapave® as a surface cover over 23 inches of crushed limestone base course for rapid runway repair.

(2) Amalgapave®. Amalgapave® is a commercial cold mix asphalt patching material packaged in 50-pound bags. The bags for this test had been stored on wooden pallets outdoors and covered with a plastic cover during the winter months. The bags of asphalt had hardened and had lost their workability, which created difficulties in spreading the asphalt.

(3) Procedure. An existing crushed limestone base course prepared in item 19, and subjected to 150 coverages of the F-4 load cart, was leveled to 1 inch below the surface of the adjacent concrete. Approximately 120 bags of hardened asphalt were uncovered and placed on the surface of the pit, and compressed with 20 passes of the RayGo 510A vibratory compactor to a level even with the concrete pad (Figure 50).

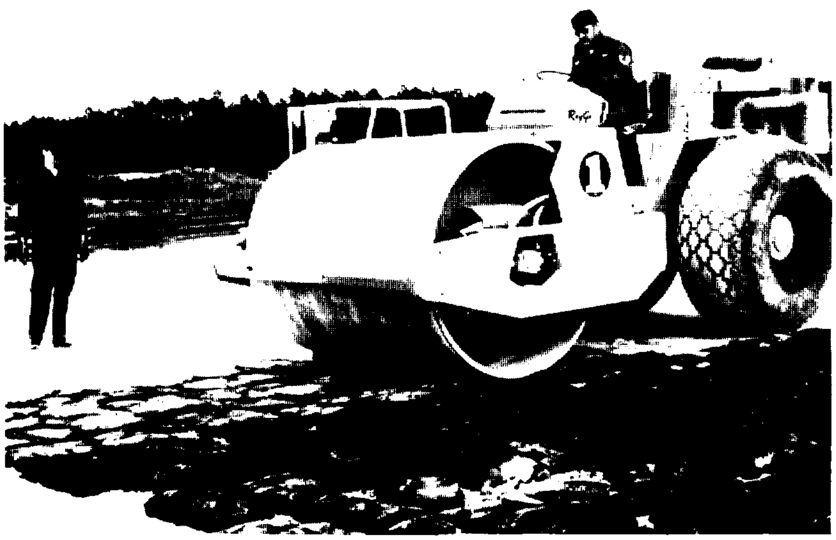


Figure 50. Compaction of Amalgapave®, Item 20

Shoving under the roller was occurring, and numerous cracks appeared on the surface of the asphalt due to the low adhesive ability.

(4) Results. During the initial coverages of the F-4 load cart, the asphalt was not bonding to the base course and the test material [illegible] to shove and pull up under the wheel of the load cart. The asphalt

was being pushed onto the concrete pad and had to be shoveled back into the pit, creating a FOD problem. Rutting and small amounts of loose gravel being pushed out of the pit became more severe after 40 coverages and grew progressively worse as the coverages increased. After 150 coverages the asphalt had broken into individual pieces 12 to 18 inches long, causing more loose gravel and chunks of asphalt to leave the pit, thus creating a more dangerous hazard to aircraft (Figure 51).

Figure 51. Surface Condition of Amalgapave®, Item 20

Table 14 has the results of the density readings taken before and after load cart coverages. Surface profiles are shown in Figure 52.

TABLE 14. MEASUREMENTS, TEST ITEM 20, 1 INCH AMALGAPAVE® OVER 23 INCHES OF CRUSHED LIMESTONE BASE COURSE

IN TRAFFIC LANE				
F-4 COVERAGES	DEPTH (In.)	WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)
0	4	156.9	149.1	5.2
	8	159.1	151.9	4.7
	12	161.3	153.6	5.0
150	4	159.0	152.4	4.3
	8	160.6	154.3	4.1
	12	161.4	154.7	4.3

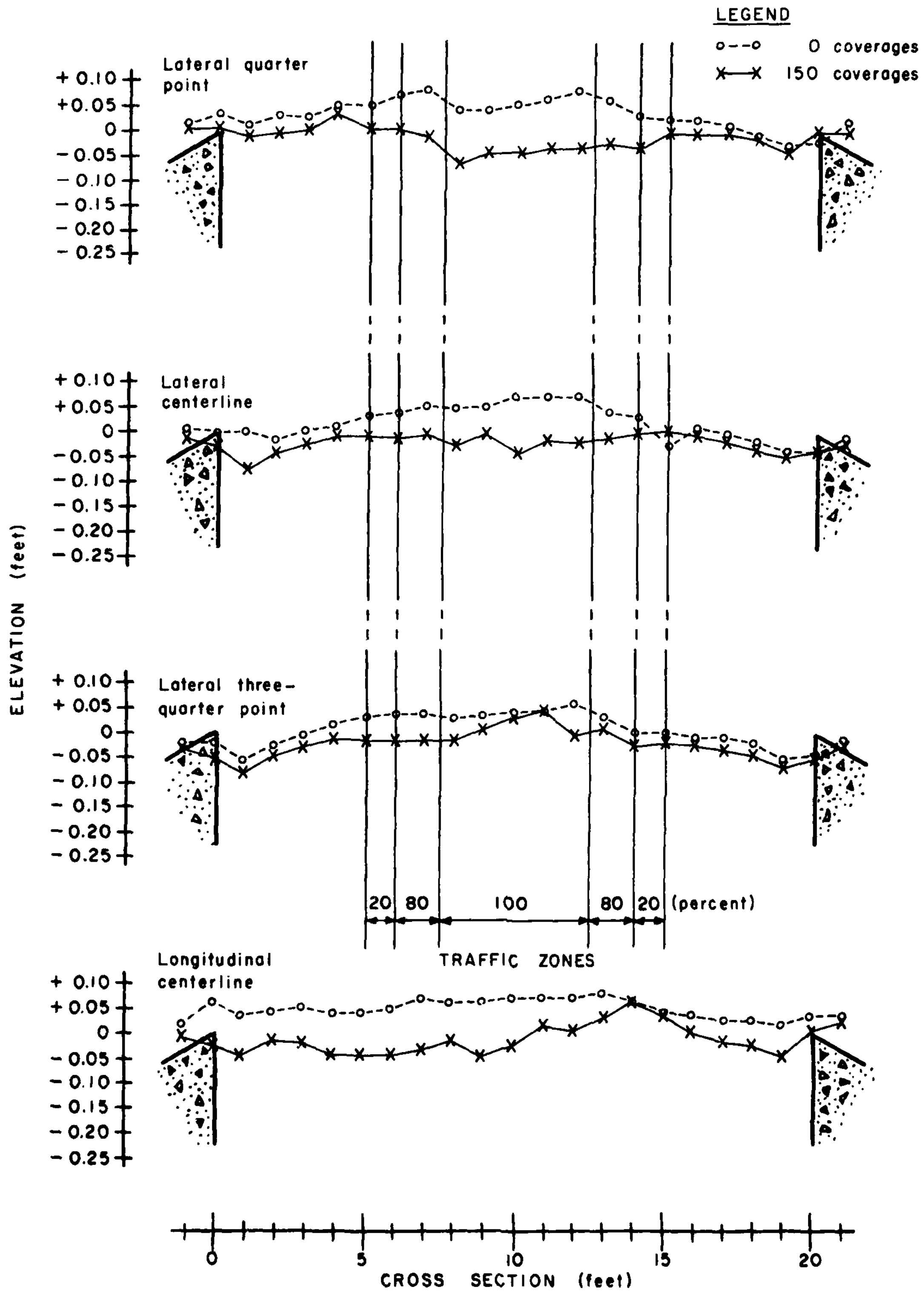


Figure 52. Surface Profiles, Item 20

Though not an entirely fair test for the Amalgapave®, it does show the problems inherent to long-term storage under adverse conditions.

The application of Amalgapave® as a surface cover over a base course to prevent FOD proved unsuccessful, mainly because of a lack of stability. The asphalt shoved and rutted severely during trafficking, thus constituting a FOD problem to aircraft.

b. Item 23 - One Inch Amalgapave® FOD Cover over Crushed Limestone Subjected to C-141 Load Cart Traffic

(1) Objective. The surface constructed for item 20 was used to test the effect of 150 coverages of the C-141 load cart.

(2) Procedure. The crushed limestone base course used in this experiment had previously seen 150 coverages of the F-4 load cart as test item 19, and after application of the 1 inch Amalgapave® FOD cover (item 20), had received an additional 150 F-4 coverages. The condition of the surface when C-141 load cart traffic commenced is shown in Figure 53.

Figure 53. Surface of Item 23 After 150 F-4 Coverages and Prior to C-141 Load Cart Trafficking

(3) Results. The C-141 load cart completed 150 coverages without any repairs being made to the test surface. The heavy load cart had compressed the Amalgapave® cover and made it appear in better condition than before the test began. Cracks had become less severe and loose surfacing material had diminished although it still presented a potential

FOD problem. Moisture and density readings are displayed in Table 15.

TABLE 15. BASE COURSE AND SUBGRADE TEST RESULTS, ITEM 23

Depth	In-Traffic		Out-of-Traffic	
	CBR	k	CBR	k
0	124	ND	126	ND
24	4	53	6	ND

ND No Data

CBR data obtained at the conclusion of testing are given in Table 16. Figure 54, showing the surface after C-141 load cart traffic, provides an indication of the unsuitability of Amalgapave® as a FOD cover in making expedient crater repairs.

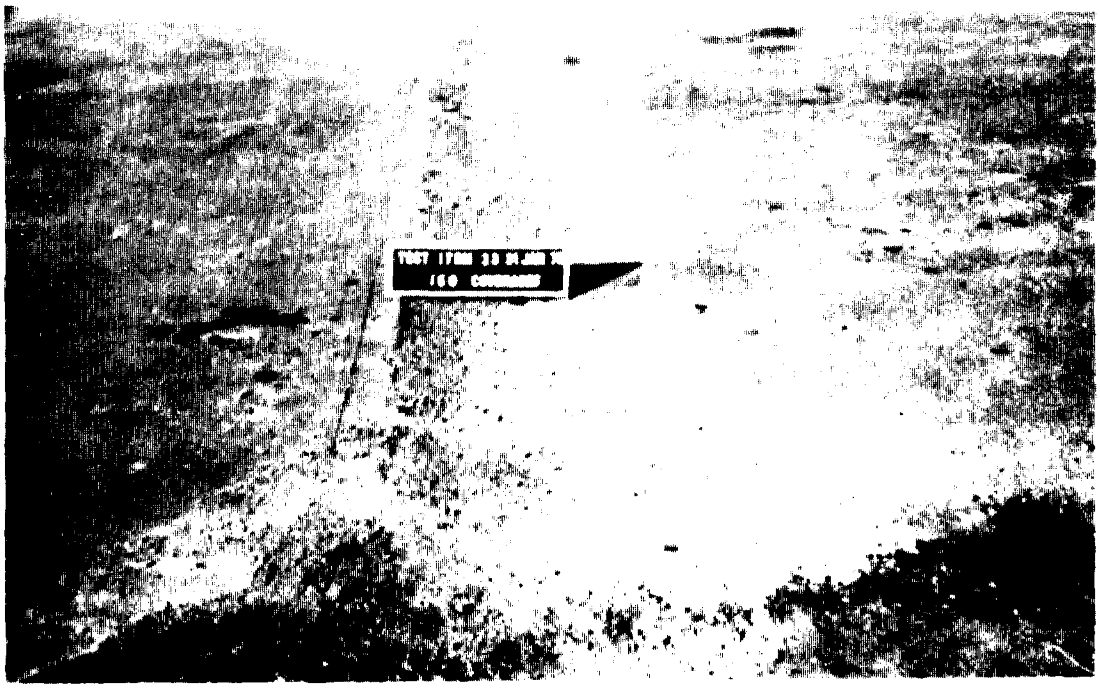


Figure 54. Surface After Traffic, Item 23

Profiles of the surface (Figure 55) indicate a consolidation of approximately 0.5 inch. Results of test item 23 support previous data which had shown that after approximately 40 coverages the amount of consolidation of the limestone base course is minimal.

TABLE 16. MEASUREMENTS, TEST ITEM 23, 1 INCH AMALGAPAVE® OVER 23 INCHES CRUSHED LIMESTONE BASE COURSE

C-141 COVERAGES	DEPTH (In.)	IN TRAFFIC LANE			OUT OF TRAFFIC LANE		
		WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)	WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)
0	4	ND	ND	ND	153.6	146.8	4.6
	8				152.8	145.8	4.8
	12				152.2	145.6	4.5
20	4	150.4	150.6	4.5	ND	ND	ND
	8	153.6	147.3	4.3			
	12	150.8	144.2	4.6			
150	4	161.4	157.0	2.8	153.8	149.6	2.8
	8	162.2	158.1	2.6	155.6	151.5	2.7
	12	163.0	158.7	2.7	156.9	152.8	2.7
150	16	154.7	150.3	2.9	ND	ND	ND
	20	156.1	151.7	2.9			
	24	156.4	152.0	2.9			

ND No Data

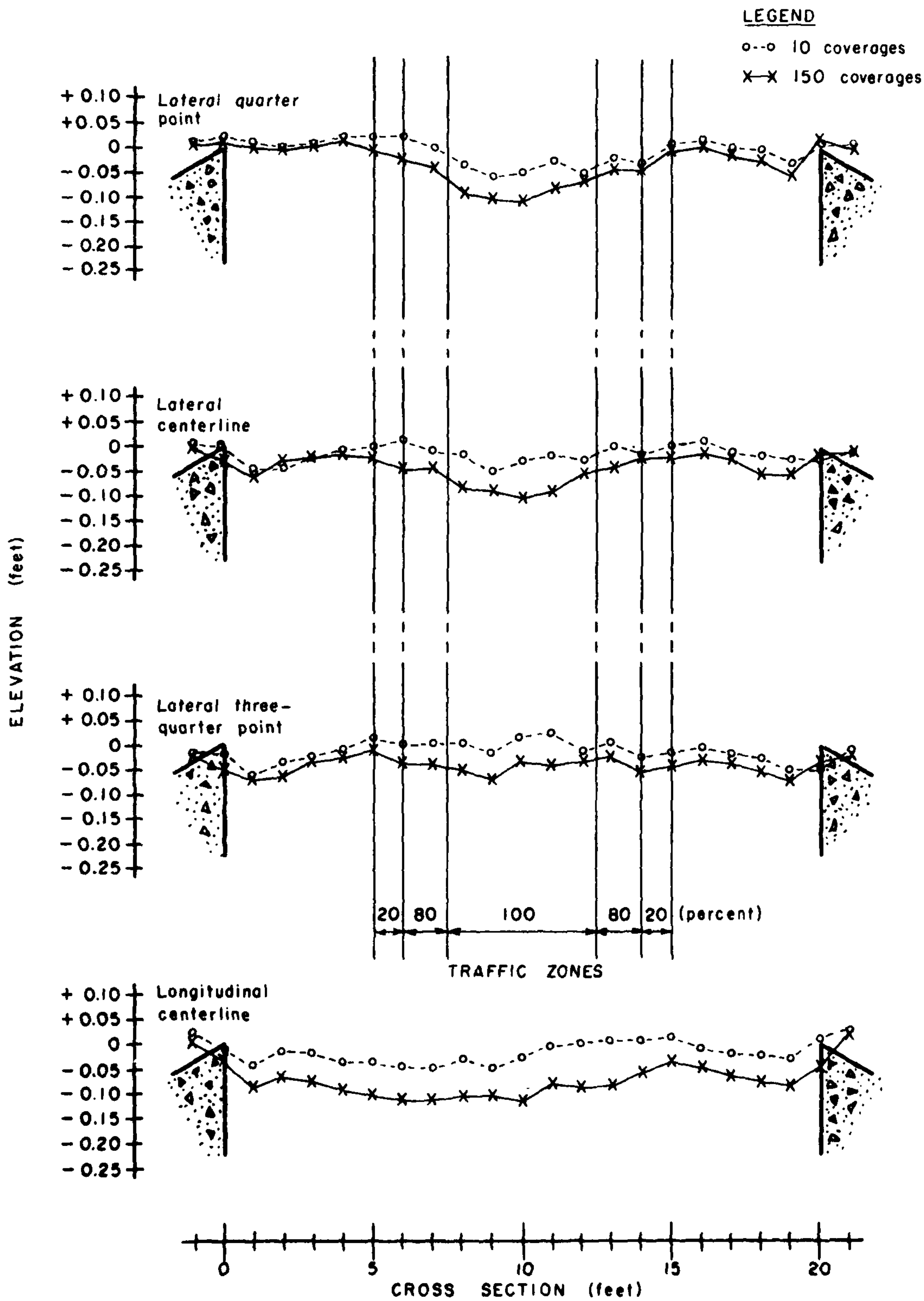


Figure 55. Surface Profiles, Item 23

c. Item 31 - T-17 Membrane FOD Cover over Crushed Limestone

(1) Objective. The objective of this item was to test the durability of the T-17 membrane emplaced over a crushed limestone base course when subjected to simulated aircraft traffic.

(2) Procedure. The base course consisted of 24 inches of crushed limestone compacted with 32 coverages of the RayGo 400A roller. Moisture content of the limestone after compaction was 1.2 percent at a depth of 4 inches with a dry density of 144.4 pcf.

It was necessary to clean the concrete surface adjacent to the test pit with blasts from a heavy duty air compressor to enable the glue to bond the membrane to the concrete surface. Brooms could not accomplish this task satisfactorily. The T-17 membrane was then stretched over the test pit and glued to the concrete surface. Glue which is provided in the T-17 kit was applied to an area approximately 2 inches wide surrounding the pit. A small test section was constructed by wrapping two opposite edges of the membrane around 0.125-inch (1/8-inch) thick pieces of flat steel and attaching them to the concrete with a ram set tool. The test section was designed to measure the effect of traffic on the membrane and the methods of attachment.

(3) Results. After 20 coverages of the F-4 load cart, ruts of 2 inches had occurred and the limestone mat had been pushed onto the edges of the concrete under the membrane causing a lip, presenting a problem when the load cart entered and exited the pit. After 30 coverages, consolidation of the base course necessitated repairs. The membrane held by the glue, was loosened on three sides and peeled back. Crushed limestone was added and the membrane replaced with only the trafficking edges reglued. A 4-inch cut in the membrane was noticed after 32 coverages. Since there are no sharp edges on the wheel portion of the F-4 load cart, it is assumed that the cut was inadvertently caused by the vibratory roller. After 58 coverages, similar repairs were again necessary. The membrane was reglued close to the edge of the pit to eliminate recurrence of the lip. Mechanical problems with the F-4 load cart caused a termination of trafficking after 72 coverages; traffic was resumed using the C-141 load cart.

After 40 coverages of the C-141 load cart, the membrane was showing a slight amount of wear, especially in the areas where creases were present and where the tires had traveled over rocks beneath the membrane. A 1-inch lip that developed on the edge of the traffic lane broke the bond between the membrane and the concrete. The edge was reglued and trafficking continued until 150 coverages were completed. A total of 72 coverages by the F-4 load cart and 150 coverages by the C-141 load cart were achieved.

The consolidation of the base course and the lip that developed on the edge of the concrete (Figure 56) required the removal of the membrane on several occasions, and subsequent regluing of the membrane to an unclean surface failed to achieve proper bonding.

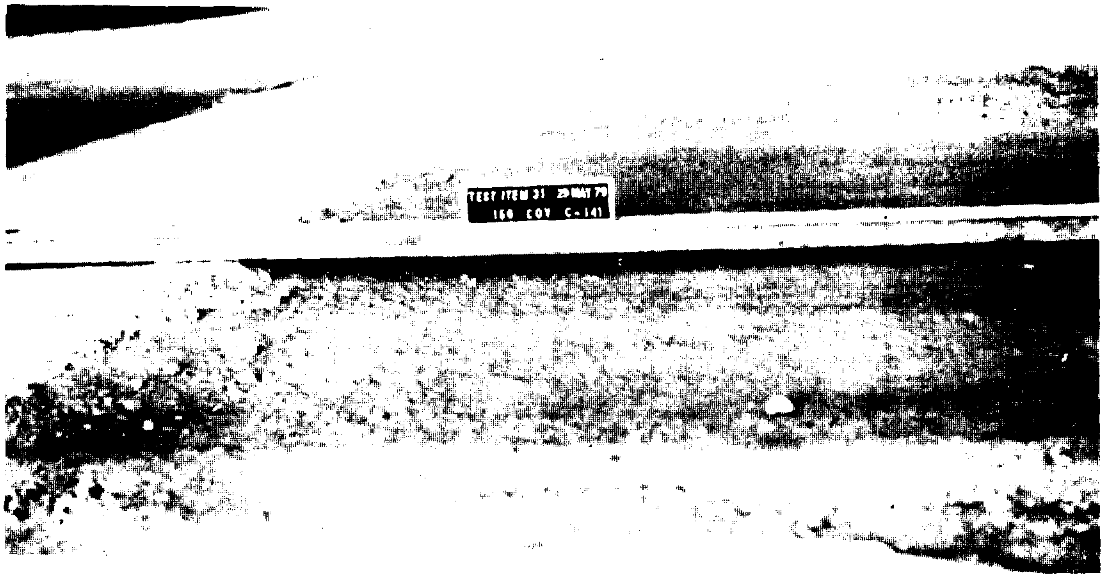


Figure 56. Consolidation of Base Course, Item 31

There was flaking on the membrane, and paper-thin pieces of membrane peeled loose on three sides (Figure 57).

Figure 57. Flaking of Membrane, Item 31

The pivoting of the load cart wheels caused much of the wear previously described. The small test section using the flat steel tie-downs held firmly and showed no unusual wear; however, it did not receive the full load cart traffic to which the larger test item was exposed. Profiles of the test surface are illustrated in Figure 58; moisture and density readings are recorded in Table 17.

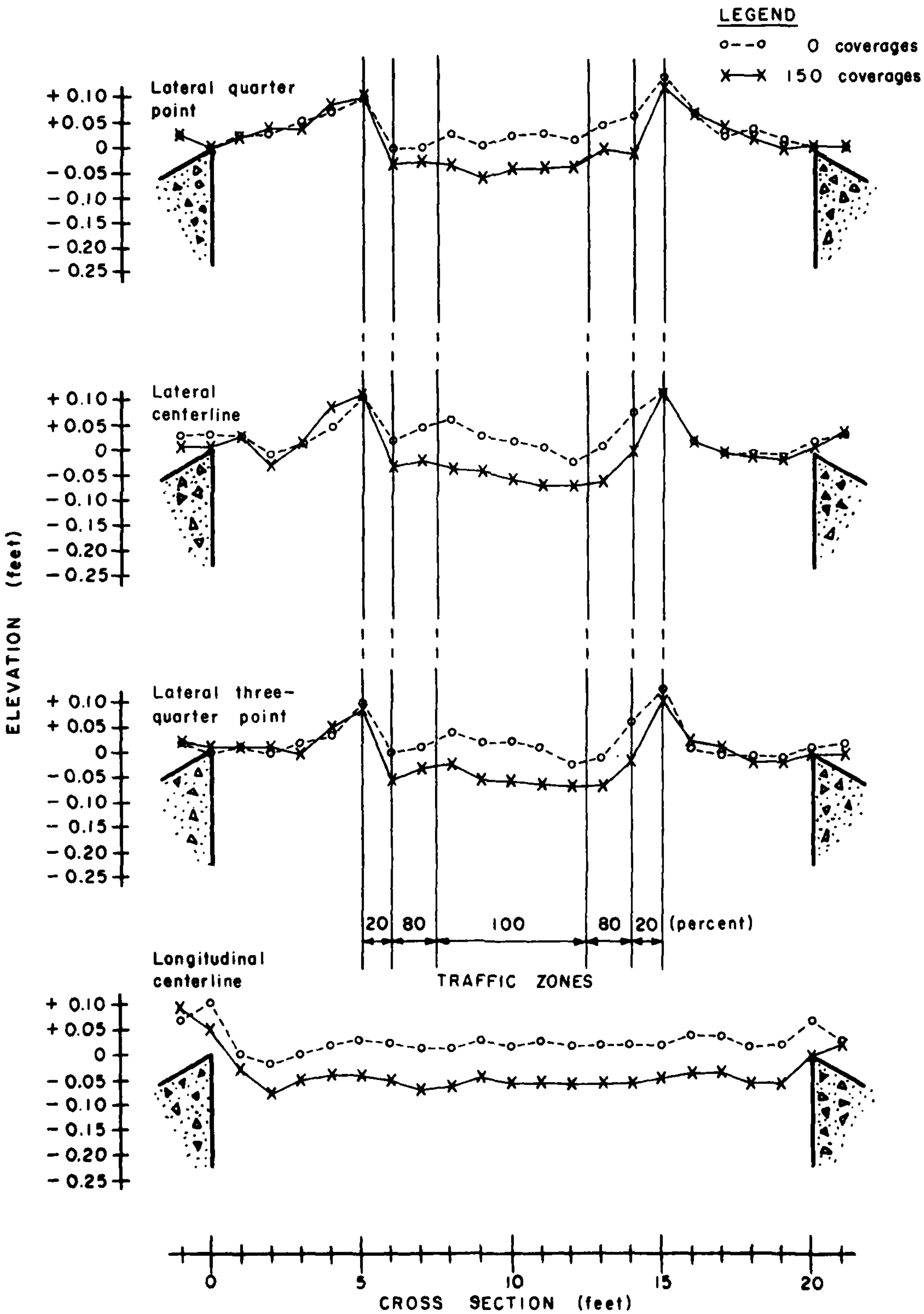


Figure 58. Surface Profiles, Item 31

TABLE 17. MEASUREMENTS, TEST ITEM 31, T-17 MEMBRANE OVER 24 INCHES CRUSHED LIMESTONE BASE COURSE

F-4 COVERAGES	DEPTH (In.)	IN TRAFFIC LANE			OUT OF TRAFFIC LANE		
		WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)	WET DENSITY (PCF)	DRY DENSITY (PCF)	MOISTURE CONTENT (%)
0	4	144.4	142.7	1.2	ND	ND	ND
	8	142.6	140.9	1.2			
	12	142.0	140.5	1.1			
	28	123.9	147.6	24.6			
	32	125.1	100.9	24.0			
	36	125.6	101.0	24.4			
72	4	146.3	144.4	1.3	ND	ND	ND
	8	149.3	147.4	1.3			
	12	149.7	147.9	1.2			
C-141 150	4	150.1	147.9	1.5	141.8	140.0	1.3
	8	151.5	149.1	1.6	141.6	139.6	1.4
	12	153.0	151.0	1.3	139.5	137.7	1.3

ND No Data

d. Item 34 - One Inch Flexible Polymer Concrete FOD Cover over 23 Inches of Crushed Limestone

(1) Objective. This experiment was designed to test the suitability of a modified polymer concrete product to serve as a FOD cover over a limestone base course. An inherent objective was to test the ability of this flexible, asphalt-like FOD cover to permit up to 2 inches of consolidation of the stone without cracking.

(2) Pre-test Experimentation. Since Silikal® polymer concrete in its normal composition could not be used due to its high modulus of elasticity, four pre-tests were conducted to determine the following:

(a) Percentage of butyl acrylate (BA) in test solution;

(b) Bonding capacity of polymer concrete;

(c) Elasticity of hardened polymer;

(d) Suitability of pea gravel for a base course.

Two 3-foot-square pits with depths of 1 inch were prepared. One pit employed compacted pea gravel, and the other employed a crushed limestone base course. Four 30-pound bags of neat Silikal® were used to fill each test pit. Before mixing the components, 30 percent of the 1/2-gallon container of R-17 liquid was removed and replaced with the same percentage of butyl acrylate. The polymer concrete was then placed over the crushed limestone pit and the pea gravel pit. A cover of polyethylene material was placed over the surface. Some of the polymer concrete had leaked into voids in the pea gravel leaving these areas without sufficient concrete to polymerize. The ambient temperature was 74.4°F.

Two hours after the polymer had been poured, ten coverages with the C-141 load cart were made across the two pre-test areas. There were depressions of 0.5 inch on both outside edges of the pits. It was found that the hardened polymer concrete in the pea gravel pit had separated from the base course.

The experiment was repeated, this time using crushed limestone as the base course in both pits. The monomer of the first test pit consisted of 80 percent MMA and 20 percent BA. The second received an 80-percent R-17 liquid and 20-percent BA mix. After 20 passes with the C-141 load cart, no damage was noted to the test materials. The forms enclosing each test pit were removed, and the hardened polymer was then placed on a hammer, the tool being in the center of the test item. All four corners were then weighted down to the ground. When the weight pressure was relieved, the test material sprang back to its original form. Both test items from the second experiment worked satisfactorily. Comparison of the results of the two pre-tests showed that the 80-percent R-17 liquid and 20-percent BA mix was superior in all desired aspects. The latter mixture was then used for the subsequent field test of the flexible polymer concrete FOD cover.

(3) Field Test

(a) Procedure. The crushed limestone base course was placed into the test pit and compacted to a level 1 inch below the surface of the surrounding concrete with 32 coverages of the RayGo 400A roller.

Fifteen men were used in the field test: six mixed and poured the polymer concrete, one recorded temperatures, six supplied materials, and two men performed the screeding. Fifty-five minutes were required to mix, pour, and screed the surface. Peak temperature of 131°F was recorded 25 minutes after the initial mixing had started. The test item was allowed to cure for 2 hours before F-4 load cart traffic commenced.

(b) Results. After ten coverages, consolidation of 1 inch had occurred and repairs to the surface became necessary. Neat Silikal® was used to fill the depressions and restore the surface to a level even with the surrounding concrete (Figure 59).

Figure 59. Surface Repair, Item 34

The test surface was profiled after 20 coverages (Figure 60). After 40 coverages, a small hairline crack developed along the edge of the traffic lane. A deflection of 0.25 inch was recorded after 60 coverages but did not increase during the remainder of the test; however, several longitudinal hairline cracks had developed. Profiles obtained at the conclusion of trafficking are shown in Figure 61.

Ten days later, the test surface was trafficked by ten coverages of the C-141 load cart to determine whether the surface had become brittle or inflexible. The surface remained flexible; only

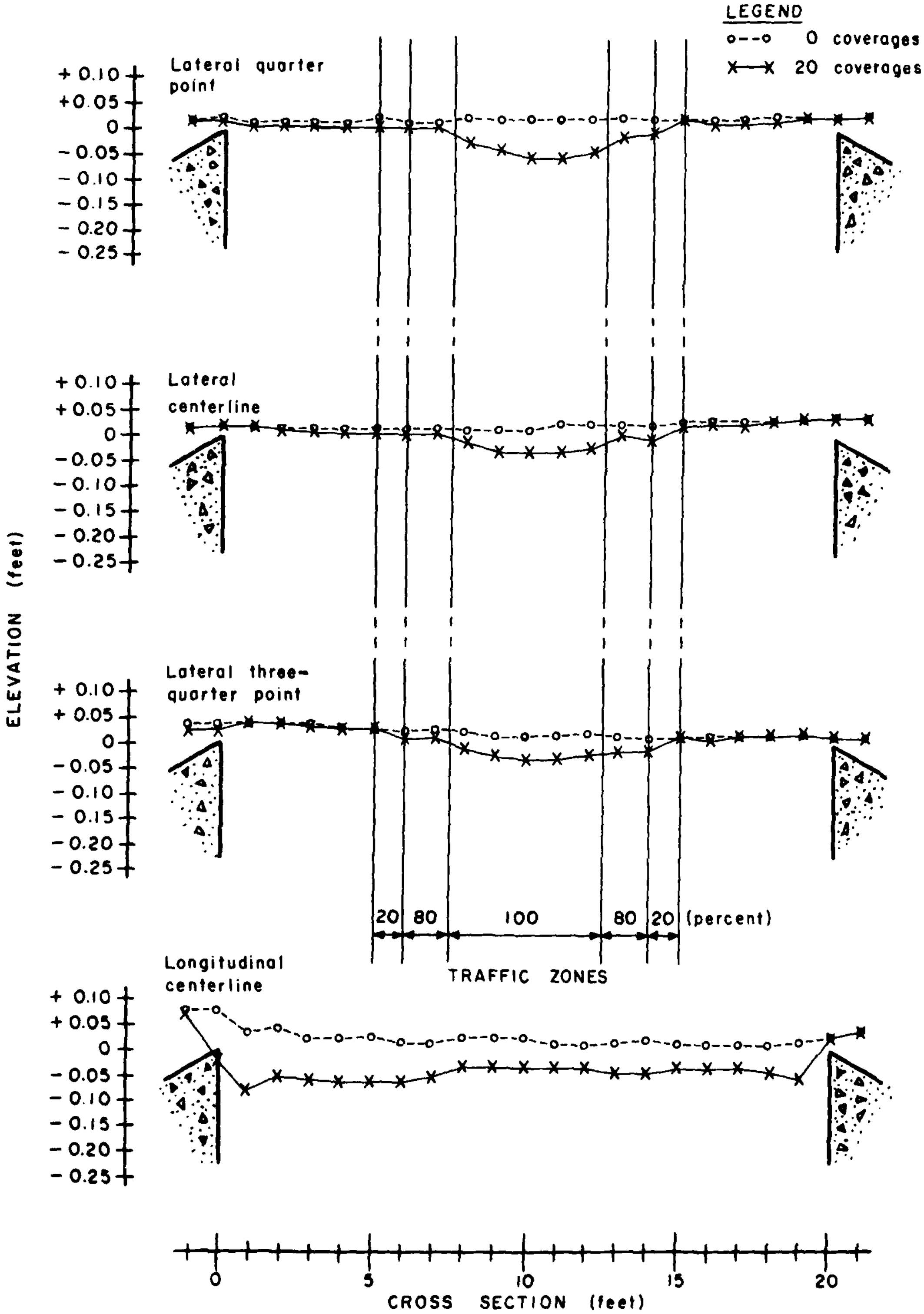


Figure 60. Surface Profiles Prior to Trafficking and After 20 Coverages, Item 34

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FIELD TEST OF EXPEDIENT PAVEMENT REPAIRS (TEST ITEMS 16-35).(U)
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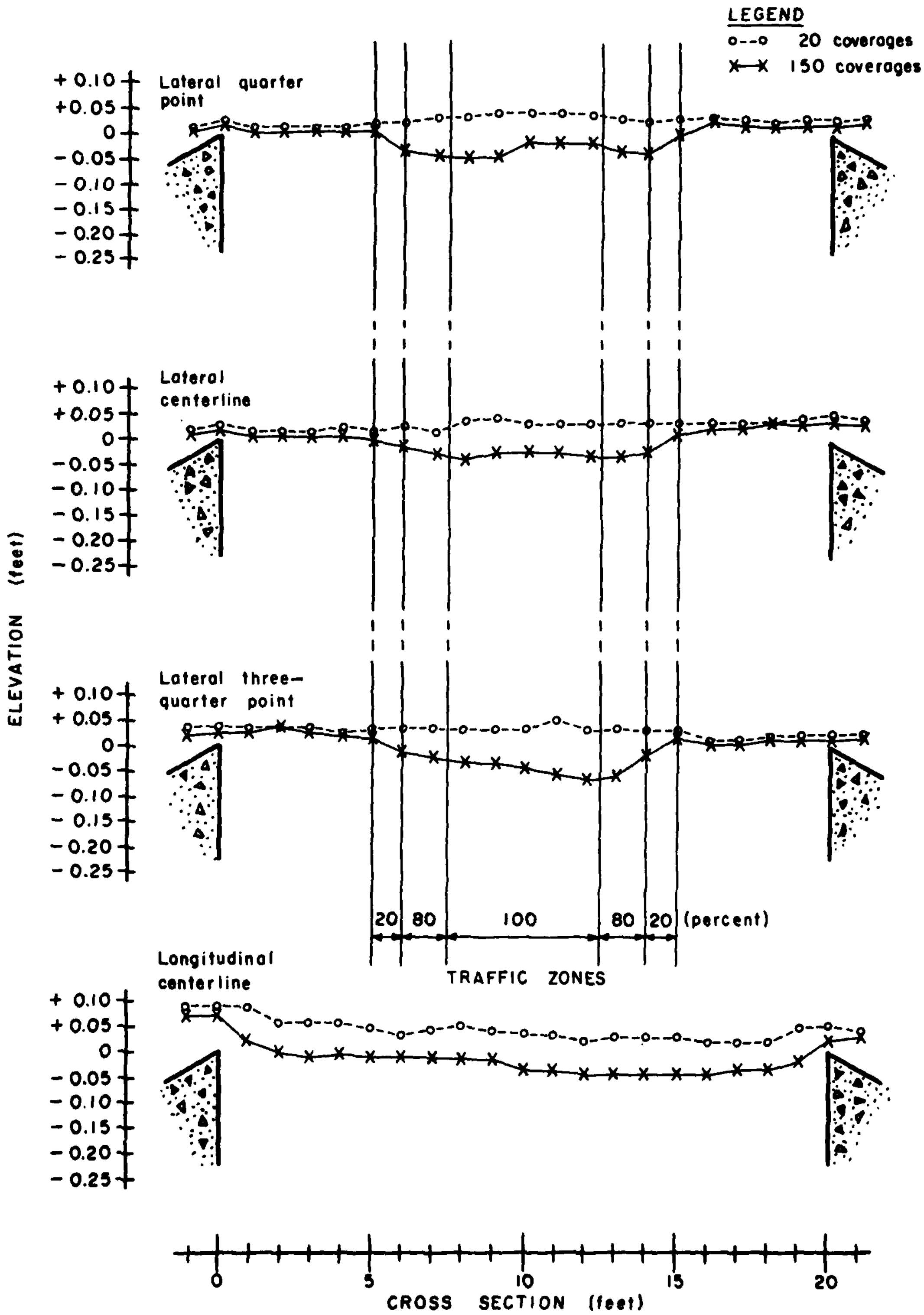

Figure 61. Surface Profiles After Repairs, Item 34

the hairline cracks on the edge of the traffic lane increased slightly in size (Figure 62). The consolidation had increased to 0.5 inch.

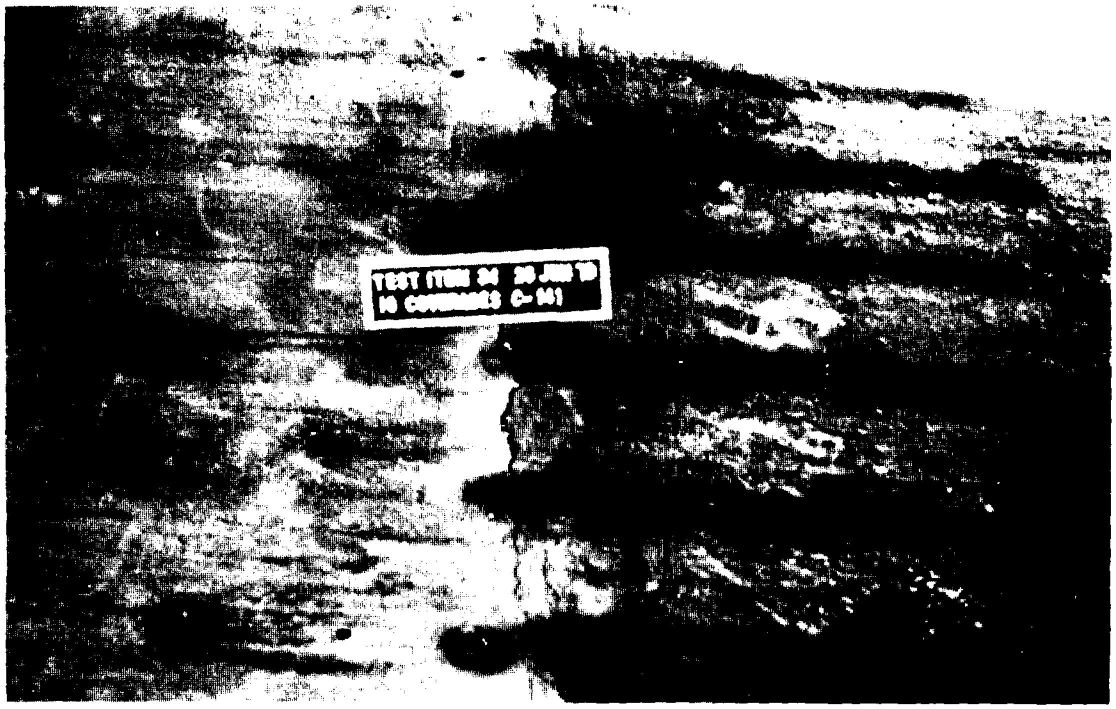

Figure 62. Cracking of Bond, Item 34

The test was considered a success. Noteworthy are the easy flow of the test material into the test pit and the uncomplicated method of repairs performed by the crew. This test item showed great potential as a candidate for expedient runway repairs.

e. Item 29 - 5 Inches of Fiberglass-Reinforced Polyurethane (FRP)

(1) Objective. The objective of this test was for the U.S. Navy Civil Engineering Laboratory to determine if this FRP foam concept would withstand F-4 traffic in connection with the ongoing efforts at Port Hueneme to support the Marine Corps Expedient Paving System.

(2) Background. This test item was not intended as a rapid runway repair concept but was tested at Tyndall AFB with test item 30 for economy of testing. The test item took CEL personnel approximately 7 days to construct. It was constructed with one-of-a-kind prototype equipment, and testing was designed to compare to AM-2 mat requirements rather than expedient repairs. Complete information on this test can be found in Reference 26.

(3) Results. The clay subgrade was placed 5 inches below the surface of the concrete and compacted to a CBR of 6. A layer of polyethylene and chopped strand fiberglass mat were placed on the clay. Approximately 5 inches of fiberglass-reinforced rigid polyurethane foam with a bonded wearing surface of 0.25-inch fiberglass-reinforced polyester (FRP) mat were constructed in place. The process was plagued with equipment problems. The F-4 load cart trafficked the repair for 190 coverages until testing was halted due to failure in the mat.

f. Item 30 - 0.5-Inch-Thick Fiberglass-Reinforced Polyester (FRP) Membrane

(1) Objective. This item was designed to test the feasibility of using an 0.5-inch-thick FRP membrane over a 24-inch-deep base course of crushed limestone and a subgrade of clay for use as a FOD cover.

(2) Background. This test item was designed and installed by the U.S. Navy Civil Engineering Laboratory at Port Hueneme, California. A complete description of this test was published as TN No. N-1572 (Reference 27).

(3) Procedure. The 24-inch base course was compacted with 32 coverages of the RayGo 400A vibratory roller at a moisture content of 3.8 percent. Soil strain sensors were placed in a vertical stack with sensors in parallel and coaxial alignment and with gauges located at 6-inch intervals to a depth of 18 inches below the upper surface of the base course. Sensor cables were buried within the subgrade.

(4) Construction of FRP Membrane. The 22-foot-square FRP membrane was fabricated on the concrete adjacent to the test pit. The membrane consisted of four layers of 4020-weight (40-ounce-per-square-yard woven roving and 2 ounces per square foot chopped strand) fiberglass mat. Total membrane thickness was 0.5 inch. Fifteen-pound roofing felt and mold release paper were placed under the membrane to avoid adherence of the polyester resin to the concrete. The fiberglass was packaged in rolls 78 inches wide, which necessitated lapping of strips of fiberglass mat to achieve a finished width of 22 feet. Adjacent fiberglass strips were overlapped by 8 inches.

Two layers of fiberglass were positioned and saturated with polyester resin (PPG Industries RS 50338) and immediately rolled with an aluminum roller to expel trapped air in the laminate. A third and fourth layer of fiberglass, applied in the same fashion, completed membrane construction. Time of gelation was approximately 1 hour. A long gel time is critical since less shrinkage of the laminate is associated with a slow cure. Gelation did not begin until all fiberglass had been positioned, thus providing the membrane with sufficient weight to prevent warping which would have accompanied a fast cure and low laminate weight.

After fabrication, a towbar was fastened to one side of the membrane and a front-end loader positioned the membrane over the

pit. The membrane was then secured to the concrete with 0.5- by 3-inch torque-set type rock bolts. The bolts were set 4 feet on-center along the membrane perimeter. Two 4-inch-square pieces of fiberglass mat were laminated to the membrane at each bolt location to provide a flush surface at the bolt heads.

(5) Results. Trafficking with the F-4 load cart commenced and continued until the 80th coverage, when the test item was removed to demonstrate the mobility of the FRP membrane. Since the surface had settled 1 inch during trafficking, 1.5 cubic yards of crushed limestone were added, compacted, and graded to restore the base course to the grade of the surrounding pavement. The membrane was repositioned over the test pit, fastened, and traffic resumed for a total of 150 coverages. After completion of trafficking with the F-4 load cart, an additional 20 coverages with the C-141 load cart were applied.

Throughout both load cart applications, the FRP membrane performed exceptionally well, and remained completely serviceable without any indication of failure or wear. The membrane prevented any rutting of the base course. Deflection during simulated aircraft loading never exceeded 0.125 (1/8) inch. It was noted that only the crushed limestone compacted during trafficking by the load carts. Permanent deformation of the FRP membrane did not occur; the membrane performed elastically throughout trafficking.

SECTION V

ANALYSIS

1. SUMMARY

Table 18 summarizes the results of testing accomplished in the second half of Phase 2, test items 16 through 35. Of the eighteen differing expedient repair designs, nine were rated successful, two were marginally effective, and five were termed failures. One of the two tests conducted by Navy CEL personnel was not designed for RRR purposes and is not included in the tabulation.

2. POLYMER CONCRETE

Polymer concrete material was used in the design of four structural cap systems. Variations in polymer concrete formulations, thickness, mixing, and application methods characterized these experimentations. Two items (16 and 35) were able to withstand the required 150 coverages of the F-4 load cart and were thus termed successful. Despite the great potential of polymer concrete as an expedient runway repair material, the analysis of test results points out the recurrence of problems associated with application of polymer concrete in the field. Mechanical mixing proved cumbersome and, in the case of the transit mix truck experiment, impracticable due to rapid hardening of the material. Screeding of the polymer concrete proved equally troublesome due to rapid curing of the material.

3. CRUSHED LIMESTONE

The nine tests examining the suitability of 1 1/2-inch crushed limestone as an unsurfaced base course material clearly underline the importance of moisture content in soil compaction. Items which exceeded the failure criteria invariably showed a moisture content in excess of 5.0 percent. These tests also demonstrated that heavy, self-propelled vibratory rollers can compact a 24-inch lift of crushed limestone to sufficient density to support at least minimal F-4 traffic--20 to 40 coverages--before repairs become necessary. Subsequent repair of the test item proved to be an effective means to extend the life of the item to withstand 150 coverages or more. In essence, however, moisture content is still seen as the dominant factor in determining success or failure of a crushed limestone repair.

4. FOREIGN OBJECT DAMAGE (FOD) COVERS

Three FOD cover designs were rated successful, having withstood in excess of 150 coverages of load cart traffic.

a. T-17 Membrane

The T-17 membrane was able to withstand the combined F-4 and C-141 coverages successfully. There was no FOD problem encountered during

TABLE 18. SUMMARY OF TEST RESULTS

Item	Thickness (in)	Surface	Coverages F-4	Coverages C-141	Results/Failure Mode
		POLYMER CONCRETE			
16	7	MMA polymer concrete structural cap	150		Success
18	3, 4, and 5	MMA polymer concrete with Dry-crete	16		Marginal. 3-Inch section failed after 142 passes
33	4.5	Silikal® polymer concrete structural cap	74		Failure; shear deformation
35	8	Silikal® polymer concrete over 2-inch aggregate	150		Success; severe flexing and FOD were encountered
		1 1/2-INCH CRUSHED LIMESTONE, UNSURFACED BASE COURSE			
19	24	Moisture Content 5.0%, RayGo 510A	150		Success; repairs required after 60 coverages
21	24	Moisture Content 5.5%, RayGo 400A	12		Failure; repaired after shear failure at 6 coverages
22	24	Moisture Content 4.6%, RayGo 400A	150		Success
24	24	Moisture Content 3.2%, RayGo 400A		150	Success; item 24 had seen 150 F-4 coverages as item 22
25	24	Moisture Content 5.6%, RayGo 510A	26		Failure; shear deformation
26	24	Moisture Content 3.0%, RayGo 400A	150		Success; repaired after 40 coverages
27	24	Moisture Content 5.5%, RayGo 510A	98		Marginal; repaired after 48 coverages, two more repairs until 98th coverage
28	24	Moisture Content 5.5%, RayGo 400A	24		Failure; repaired after 4 coverages, shear failure 24 coverages
32	24	Moisture Content 2.0%, RayGo 400A		150	Success
		FOREIGN OBJECT DAMAGE (FOD) COVERS			
20	1	Amalgapave® over 23 inches of limestone	150		Failure; unstable surface, severe cracks, FOD hazard
23	1	Amalgapave® over 23 inches of limestone		150	Failure; loose surfacing material posed FOD problem
31	0.04	T-17 Membrane over 24 inches limestone	72	150	Success; repairs required at 30, 32, and 58 F-4 load cart coverages; also after 40 C-141 coverages
34	1	Flexible (modified) Silikal® polymer concrete	150	10	Success; repaired after 10 F-4 load cart coverages
29	5	Fiberglass-reinforced polyurethane foam with 0.25-inch FRP mat as a wearing surface	190		Note 1
30	0.5	Fiberglass-reinforced polyester membrane over 24 inches limestone	150	20	Success; base course restored after 80 F-4 load cart coverages

Note 1. Navy Civil Engineering Laboratory Test Item. Not designed as a rapid repair concept.

this test. The contact cement adhesive method used in test item 31 is not recommended. The membrane should be fastened down with pieces of flat steel.

b. Fiberglass-Reinforced Polyester (FRP) Membrane

This membrane withstood the F-4 and C-141 traffic exceptionally well. The FRP membrane performed elastically throughout trafficking. No FOD problems were encountered. The field fabrication of FRP membranes would be feasible only under dry weather conditions.

c. Flexible (Modified) Silikal® Polymer Concrete

Applied over 23 inches of compacted crushed limestone, the modified Silikal® polymer concrete material showed excellent results. Repair procedures were uncomplicated, permitting expeditious completion of the test item. Laboratory and field experimentation preceding the actual field test determine the optimal composition of the monomer (80 percent R-17, 20 percent BA) to be used with the neat Silikal® product.

SECTION VI

CONCLUSIONS

1. AM-2 LANDING MAT

The fastest, most dependable and practical large crater repair method using standard inventory Air Force equipment and existing technology is still the placement of AM-2 landing mat on top of the pavement as specified in AFR 93-2.

2. SMALL CRATER REPAIR

For small craters, the two methods of repair judged to be most promising are:

a. One and one-half (1 1/2) inch size graded crushed limestone used as an unsurfaced base course, compacted at a moisture content of 2.5 to 3.0 percent with a heavy, self-propelled vibratory roller.

b. Hand-mixed Silikal® polymer concrete poured over 2- to 3-inch sized aggregate.

3. FOREIGN OBJECT DAMAGE (FOD) COVERS

If the unsurfaced limestone base course presents a FOD hazard, the following surface covers merit further development:

a. T-17 membrane.

b. Flexible polymer concrete.

c. Fiberglass-reinforced polyester (FRP) mats.

4. REPAIR PROCESS

a. Moisture Content of Limestone

Moisture content of the crushed limestone before compaction in excess of 5.0 percent will probably result in failure of the repair. Stockpiled crushed limestone will normally contain less moisture; however, an uncovered stockpile combined with an extended period of heavy rain may very well cause a critically high moisture content to be reached.

b. Material Handling

Any material which is quick setting--MMA, Silikal®, or modified Silikal® polymer concrete--requires on-site mixing. Standard inventory Air Force equipment has proven unsuitable for mechanical mixing of

polymer concrete materials. The gravity-feed system designed for test item 16, while achieving rapid distribution of the polymer liquid, created a hazardous environment due to slow percolation of the MMA in the well graded limestone, making the system impracticable for large scale field use.

SECTION VII

RECOMMENDATIONS

NOTE: Recommendations are based on work carried out between July 1978 and September 1979 and should be viewed in the context of that time frame.

1. The Phase 3* explosive crater field testing should evaluate the following small crater repair techniques:

   a. Unsurfaced crushed limestone, and

   b. Hand-mixed Silikal® polymer concrete.

*Phase 3 testing took place in July and August 1979 and is documented in a separate report, *Small Crater Expedient Repair Test* (Reference 9).

2. A study should be performed to determine if, in fact, an FOD cover is required over the crushed limestone repairs.

3. If an FOD cover is needed for the crushed limestone repair, recommend using the T-17 membrane because it is already in the U.S. Air Force supply system.

4. Continued development of an improved FOD cover system should include better anchoring methods for the T-17 membrane and improved application techniques for fiberglass surfacing and flexible polymer concrete materials.

5. Self-propelled vibratory rollers should replace all of the smaller, towed vibratory compactors in the Rapid Runway Repair kits. This will achieve better compaction for the AFR 93-2 large crater AM-2 mat repairs and also enhance the capability for small crater repairs using crushed limestone.

REFERENCES

1. AFR 93-2, *Base Recovery Planning*, Department of the Air Force, Washington, D.C., 11 December 1979.

2. Kilner, J. R., *Roughness Criteria for Bomb Damage Repair of Airfield Pavements*, CEEDO-TR-77-50, Boeing Commercial Airplanes Company, Seattle, Washington, October 1977.

3. Caldwell, L. R. and Jacobson, Frederick J., *Interim Guidance for Surface Roughness Criteria*, ESL-TR-79-37, Air Force Engineering and Services Center, Tyndall AFB, Florida, October 1979.

4. Rone, C., *Evaluation of Materials for Post-Attack Pavement Repair*, CEEDO-TR-78-16, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, September 1978.

5. Rollings, Raymond S., *Laboratory Evaluation of Expedient Pavement Repair Materials*, CEEDO-TR-78-44, Detachment 1 (Civil and Environmental Engineering Development Office), Armament Development Test Center, Tyndall AFB, Florida, June 1979.

6. Rollings, Raymond S., *Interim Report of Field Test of Expedient Pavement Repairs (Test Items 1-15)*, ESL-TR-79-08, Engineering and Services Laboratory, Air Force Engineering and Services Center, Tyndall AFB, Florida, March 1980.

7. McNerney, Michael T., *An Investigation of the Use of Polymer-Concrete for Rapid Repair of Airfield Pavements*, CEEDO-TR-78-10, Detachment 1 (Civil and Environmental Engineering Development Office), Armament Development Test Center, Tyndall AFB, Florida, January 1978.

8. McNerney, Michael T., *Interim Field Procedure for Bomb Damage Repair - Using Crushed Stone for Crater Repairs and Silikal® for Spall Repairs*, ESL-TR-79-01, Engineering and Services Laboratory, Air Force Engineering and Services Center, Tyndall AFB, Florida, April 1979.

9. Knox, Kenneth J., *Small Crater Expedient Repair Test*, ESL-TR-80-42, Engineering and Services Laboratory, Air Force Engineering and Services Center, Tyndall AFB, Florida, August 1980.

10. Brooks, George W., Cunningham, John E., and Mayer, Paul W., *Bomb Damage Repair Damage Prediction*, 2 Volumes, AFCEC-TR-75-24, Martin Marietta Corporation, Orlando, Florida, October 1975.

11. *Military Standard Unified Soil Classification System for Roads, Airfields, Embankments and Foundations*, MIL-STD-619B, Department of Defense, Washington, D.C., June 1968.

12. Brown, D. N., and Thompson, O. O., *Lateral Distribution of Aircraft Traffic*, MP-5-73-56, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, July 1973.

13. *Materials Testing*, AFM 89-3, Department of the Air Force, Washington, D.C., February 1971.

14. *Military Standard Test Method for Bituminous Paving Materials*, MIL-STD-620A, Department of Defense, Washington, D.C., May 1961.

15. *Military Standard Test Method for Pavement Subgrade, Subbase and Base Course Materials*, MIL-STD-621A, Department of Defense, Washington, D.C., December 1964.

16. *Paving and Surfacing Operations*, TM-5-337, Department of the Army, Washington, D.C., February 1966.

17. Joint Contingency Construction Requirements Study (JCCRS) Action Memorandum between the Secretary of the Air Force and the Secretary of the Army, dated January 27, 1978.

18. *Multiple-Wheel Heavy Gear Load Pavement Test-Scale Report*, Volume 1, AEWES-TR-5-71-17, Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, November 1971.

19. Shahin, Mohamed Y., Darter, Michael I., and Kohn, Starr D., *Development of a Pavement Maintenance Management System*, 2 Volumes, AFCEC-TR-76-27, U.S. Army Engineer Construction Engineering Research Laboratory, Champaign, Illinois, November 1976.

20. Womack, L. M., *Tests of the C-130E Aircraft on Unsurfaced Soils*, MP-4-712, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, February 1965.

21. Hay, Delynn R., *C-141A Jumbo Flotation Test on Landing Mat and Unsurfaced Runways - Civil Engineering Support*, AFWL-TR-70-30, Air Force Weapons Laboratory, Kirtland AFB, New Mexico, May 1970.

22. Fenwick, W. B., *F-4C Aircraft Field Test Landing Strip Evaluation*, MP-4-701, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, August 1965.

23. Yoder, E. J., and Witczak, M. W., *Principles of Pavement Design*, 2nd Edition, John Wiley and Sons, Inc., New York, New York, 1975.

24. Seed, H. B., Chan, C. K., and Lee, C. E., "Resilience Characteristics of Subgrade Soils and Their Relation to Fatigue Failure in Asphaltic Pavements," Proceedings, First International Conference on Structural Design of Asphalt Pavements, 1962.

25. Knox, Kenneth J., *Evaluation of Vibratory Roller for Bomb Damage Repair*, EDL-TR-80-43, Engineering and Services Laboratory, Air Force Engineering and Services Center, Tyndall AFB, Florida, August 1980.

REFERENCES (Concluded)

26. Springston, P. S., *Fiberglass-Reinforced Rigid Polyurethane Expedient Pavement Subject to Simulated F-4 Aircraft Traffic*, TN No. N-1578, Naval Civil Engineering Laboratory, Port Hueneme, California, 93043, May 1980.

27. Springston, P. S., *Traffic Testing of a Fiberglass-Reinforced Polyester Resin Surfacing for Rapid Runway Repair*, TN No. N-1572, Naval Civil Engineering Laboratory, Port Hueneme, California, 93043, February 1980.

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APPENDIX A

MANUFACTURER'S DATA ON VIBRATORY COMPACTORS

	RayGo 400A	RayGo 510A
Machine Shipping Weight (lb)	20,000	33,500
Drum Weight (lb), Estimated	11,000	18,425
Rated Dynamic Force (lb) (Generated at Maximum Frequency Unless Otherwise Noted)	27,000	45,000
Weight Per Lineal Inch of Drum Width (lb), Estimated	131	230
Frequency Range, VPM	1100 - 1500	1100 - 1500
Number of Amplitude Settings	1	1
Drum Diameter, Inches	59	60
Drum Width, Inches	84	80

APPENDIX B

LIST OF MANUFACTURERS

Silikal North America, Inc.
305 Orange Street
Bridgeport, Connecticut 00607

Product Name: Silikal® R-7/R-17 Powder; Silikal® R-17 Liquid

Bray Oil Co.
1925 N. Marianna Avenue
Los Angeles, California 90032
(213) 268-6171 - Mr. Eugene Slaby

Product Name: Amalgapave®

INITIAL DISTRIBUTION

DTIC-DDA-2	12
HQ AFSC/DLWM	1
HQ AFSC/SDNE	1
HQ AFSC/DEE	1
HQ AFSC/DEM	1
HQ USAFE/DEMY	2
HQ USAFE/DEM	2
HQ USAFE/EUROPS (DEXD)	2
AFATL/DLJK	1
AFATL/DLODL	1
AD/IN	1
USAFTAWC/RX	1
USAFTAWC/THL	1
USAFTAWC/THLA	1
EOARD/LNI	2
Shape Technical Center USRADCO	1
HQ PACAF/DEM	2
HQ TAC/DEE	2
HQ TAC/DRP	1
HQ TAC/DEPX	1
AUL/LSE 71-249	1
HQ SAC/DE	1
HQ SAC/DEE	1
HQ SAC/DEM	1
USN Civil Engineering Laboratory	2
US Naval Construction Battalion Center	1
NAVEODFAC	1
HQ ATC/DED	1
HQ ATC/DEE	1
HQ MAC/DEM	1
HQ AFESC/DEO	1
HQ AFESC/DEMP	1
HQ AFESC/TST	1
HQ AFESC/RDC	5
HQ AFESC/RDCR	10
HQ AFESC/RDCT	2
HQ USAFA/DFEM	1
USAE Waterways Experiment Station/WESGF	2
HQ USAF/LEEX	1
HQ USAF/LEYW	1
HQ USAF/RDPX	1
AFWAL/FIEM	1
AFWAL/FIBE	1
HQ AFLC/DEMG	1
HQ AFLC/DEE	1
AFIT/DET	1
AFIT/LDE	1
AFWAL/MMXE	2

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